

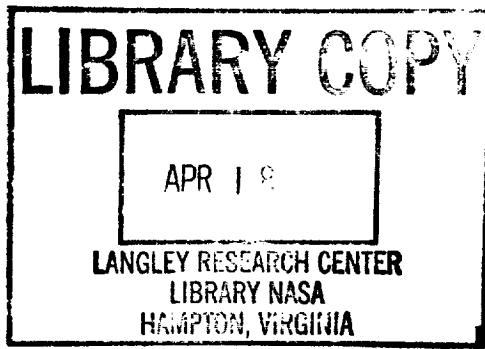
ADVANCED TECHNOLOGY ADVISORY COMMITTEE

NASA AUTOMATION AND ROBOTICS

INFORMATION EXCHANGE WORKSHOP PROCEEDINGS

VOLUME 2, PART B – PRESENTATIONS MATERIAL

Thursday and Friday Sessions



MAY 13 – 17, 1985

PREFACE

At the request of the NASA Space Station Program management, Level A of the Office of Space Station, the NASA Advanced Technology Advisory Committee (ATAC) held a workshop on advanced Automation and Robotics for all NASA Centers. The workshop was held at the Lyndon B. Johnson Space Center, Houston, Texas on May 13 through 17, 1985. The workshop addressed the research and development work in progress at the NASA Centers or under the sponsorship of the Centers. Work being done by civil servants, universities and industry personnel was all treated.

This document, Volume 2, parts A and B, of the Workshop Proceedings, presents the full papers (by presenter or other material) used for presentation in the workshop.

Volume 2, part A contains May 13 and May 14 presentations.
Volume 2, part B contains May 14-16 presentations.

See Volume 1 for:

- o A summary of workshop accomplishments and issues
- o Recommendations of the ATAC pursuant to the workshop
- o Brief descriptions of the papers presented

OBJECTIVES OF THE WORKSHOP WERE:

- Information exchange between the NASA centers on current efforts in advanced artificial intelligence, robotics, and automation.
- Identification of current efforts throughout NASA, and gaps in the current efforts, in relation to Space Station automation and robotics.

The agenda was a set of technical overview presentations from the NASA centers on current efforts in advanced artificial intelligence, robotics and automation, and a joint session with the (SSIS) workshop being held at JSC the same week.

Representatives from Headquarters, ARC, JPL, JSC, KSC, GSFC, LaRC, LeRC, MSFC and Space Station levels A, B, and C participated.

(See page 1139 for attendees list.)

Compiled By:

Artificial Intelligence and
Information Sciences Office/JSC-SR
Jon D. Erickson/Manager/713-483-4776

NOTES

See Volume 1, Executive Summary for:

- o Welcome and Introduction - Mr. Aaron Cohen, ATAC Chairman
- o Keynote Messages - Mr. Dan Herman, Director Engineering Division, OSS
- o A brief description of the intent of each presentation
- o A summary and recommendations
- o Attendees list (Both volumes)

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Automated Subsystem Control for Life Support Systems	Nick Lance	JSC 13
Systems Engineering Simulator (SES) Simulation Environment for Automation and Robotics	R. Harry St. John	JSC 23
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NASA/DARPA/AIAA Symposium on A & R and Discussion: NASA Training in A & R	Lou Clark	NASA Hdq. Code D 352

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RETURN TO: NASA AUTOMATION AND ROBOTICS INFORMATION EXCHANGE WORKSHOP

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ATAC SPACE STATION S&R WORKSHOP

STATUS OF KSC-CARGO OPERATIONS AI ACTIVITIES

EMPRESS AND PLANNET

MAY 16, 1985

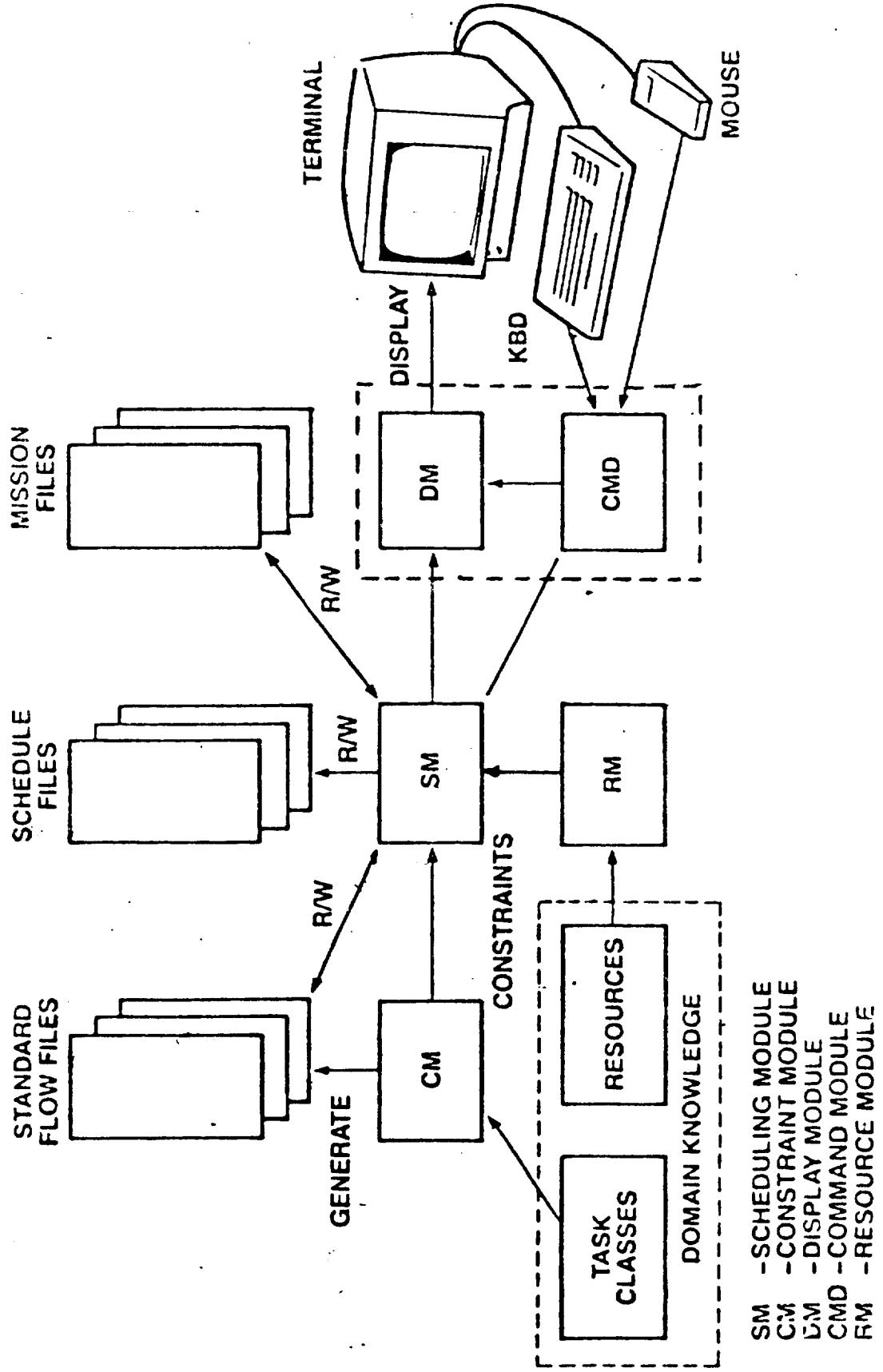
JAMES M. RAGUSA
KRISTY WETZEL
JAMES DUMOULIN

Currently KSC maintains a variety of schedules ranging from high-level, STS Flight Assignments through detailed 72 Hour/11 Day schedules. In response to proposed changes in Shuttle manifests, "what if" analyses are frequently performed using pencil and paper and a system called ARTEMIS. Typical turn-around time for ARTEMIS is 13-17 hours. Because better tools are needed by the people who do the routine scheduling for examining the impact of potential manifest changes, several expert systems for scheduling are under development at KSC.

**THE HIERARCHY OF
SCIENCE AND APPLICATION PAYLOADS
PLANNING/SCHEDULING**

SCHEDULE	SCOPE	PLAYERS (R=RESPONSIBLE FOR)	PUBLISHED
STS FLIGHT ASSIGNMENTS (MANIFEST)	<ul style="list-style-type: none"> • ALL STS MISSIONS • 5 YEARS AHEAD • CARGO BAY ONLY • SPECIFIC DATES 	<ul style="list-style-type: none"> • NASA-HQ (R) • CUSTOMERS • NASA CTRS 	MONTHLY (GOAL)
MASTER MULTI-FLOW (MULTI-MISSION)	<ul style="list-style-type: none"> • HORIZONTAL MISSIONS • 2 YEARS AHEAD • SPECIFIC DATE • ALSO KEY RESCS. 	<ul style="list-style-type: none"> • CS (R) • MDTSCO • ORBITER 	AS REQUIRED
MASTER MISSION	<ul style="list-style-type: none"> • PER MISSION • SEVERAL YRS AHEAD • ITERATED 	<ul style="list-style-type: none"> • MDTSCO (R) • CS (LV IV) • OTHERS 	ITERATED & PERIODIC
EXPERIMENT INTEGRATION (LEVEL IV)	<ul style="list-style-type: none"> • ALL LV IV ACTIVITIES • ON PER MISSION BASIS 	<ul style="list-style-type: none"> • CS (R) • MDTSCO • OTHERS 	PERIODIC
72 HOURS/ 11 DAY	<ul style="list-style-type: none"> • DAILY • MODIFIED AT DAILY MTGS. 	<ul style="list-style-type: none"> • CS (R) - LV IV • MDTSCO (R) - LV III/II • OTHERS 	DAILY
WORK/ACTIVITY	<ul style="list-style-type: none"> • AS REQUIRED • "MAKE WORK" • PROCEDURES/PARTS/TOOLS 	<ul style="list-style-type: none"> • CS(R) - LV IV • MDTSCO-LV III/II 	AS REQUIRED

EMPRESS Software Structure



M EXPERT SYSTEMS TECHNOLOGY ACTIVITIES
5/8/85

	CY 1985						CY 1986						CY 1987				CY 1988							
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
EMPRESS (KSC/MITRE)	PHASE II						PHASE III						PHASE IV						-----					
	PROTO. DEV. & TEST						DEMO						OPERATIONAL IMPLEM.						-----					
	KSC GRAPHICS						ASSESSMENT						-----						-----					
EMPRESS RELATED (KSC/MITRE)	SHUTTLE APPLICATION						DEMO						OPERATIONAL SYS. & MAINT.						-----					
	VERTICAL APPLICATION						DEMO						OPERATIONAL SYS. & MAINT.						-----					
	S.S APPLICATION						DEMO						OPERATIONAL SYS. & MAINT.						-----					
ISP/SYMBOLICS TRAINING	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆		
ART APPLICATIONS (KSC/JSC INFERENC)	SL PROCESS. DEMO						S.S PROCESS. DEMO						ASSESSMENT & MAINT.						-----					
	RQMTS. GENER.						DEMO						ASSESSMENT & MAINT.						-----					
ART TRAINING	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆		
PLANNET (MDTSCO/GT)	DEVEL. & DEMO						DEMO						DEMO FINAL						-----					
OTHER CM PROJECTS	PCU DIAGNOSTICS												PROJECT X						-----					

5 YEAR PLAN
CM EXPERT SYSTEMS TECHNOLOGY FUNDING
5/8/85

	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89
FUNDING TASKS						
MITRE-EMPRESS	\$50K	\$160K	\$50K			
PHASE I						
PHASE II						
PHASE III						
SYMBOLICS SYS.	\$135.4K	\$9K	\$10K			
SYMBOLICS TNG.	\$3.6K		\$200K	\$200K	\$100K	\$100K
HARDWARE-S/W						
TOTAL	\$190K	\$169K	\$260K	\$200K	\$100K	\$100K
E E FUNDING TASKS						
MITRE-EMPRESS	\$60K	\$100K	\$50K	\$50K	\$50K	\$50K
PHASE II (SUPP)						
PHASE III (SUPP)						
PHASE IV & ASSMT						
AUTO. PLAN SYS.	\$43K	\$100K	\$100K	\$100K	\$100K	\$100K
HARDWARE-S/W						
TOTAL	\$103K	\$260K	\$310K	\$310K	\$200K	
E S FUNDING TASKS						
INFERENCE	\$40K					
ART S/W, TNG, MAINT.	\$30K	\$15K				
CONSULT, TNG.						
S.S OPS. CONT.						
S.S. PROCESSING	\$100K	\$100K	\$75K	\$50K		
RQMTS. GENERATION	\$35K	\$50K	\$75K	\$125K		
PROCED. GENERATION						
TOTAL	\$70K	\$150K	\$200K	\$225K	\$275K	
GRAND TOTAL	\$190K	\$342K	\$670K	\$710K	\$635K	\$575K
	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89

PLANET

GOAL: DEVELOP A KNOWLEDGE BASED SYSTEM WHICH CAN SUPPORT DEVELOPMENT AND MAINTENANCE OF CARGO PROCESSING PLANS AND SCHEDULES.

OBJECTIVE: DEMONSTRATE SYSTEM APPLICABILITY OF KNOWLEDGE BASED ARTIFICIAL INTELLIGENCE TECHNIQUES TO STS CARGO PROCESSING FOR A NASA APPROVED 72 HOUR/ 11 DAY SCHEDULE WITH A GOOD MIX OF PROCESSING ACTIVITIES.

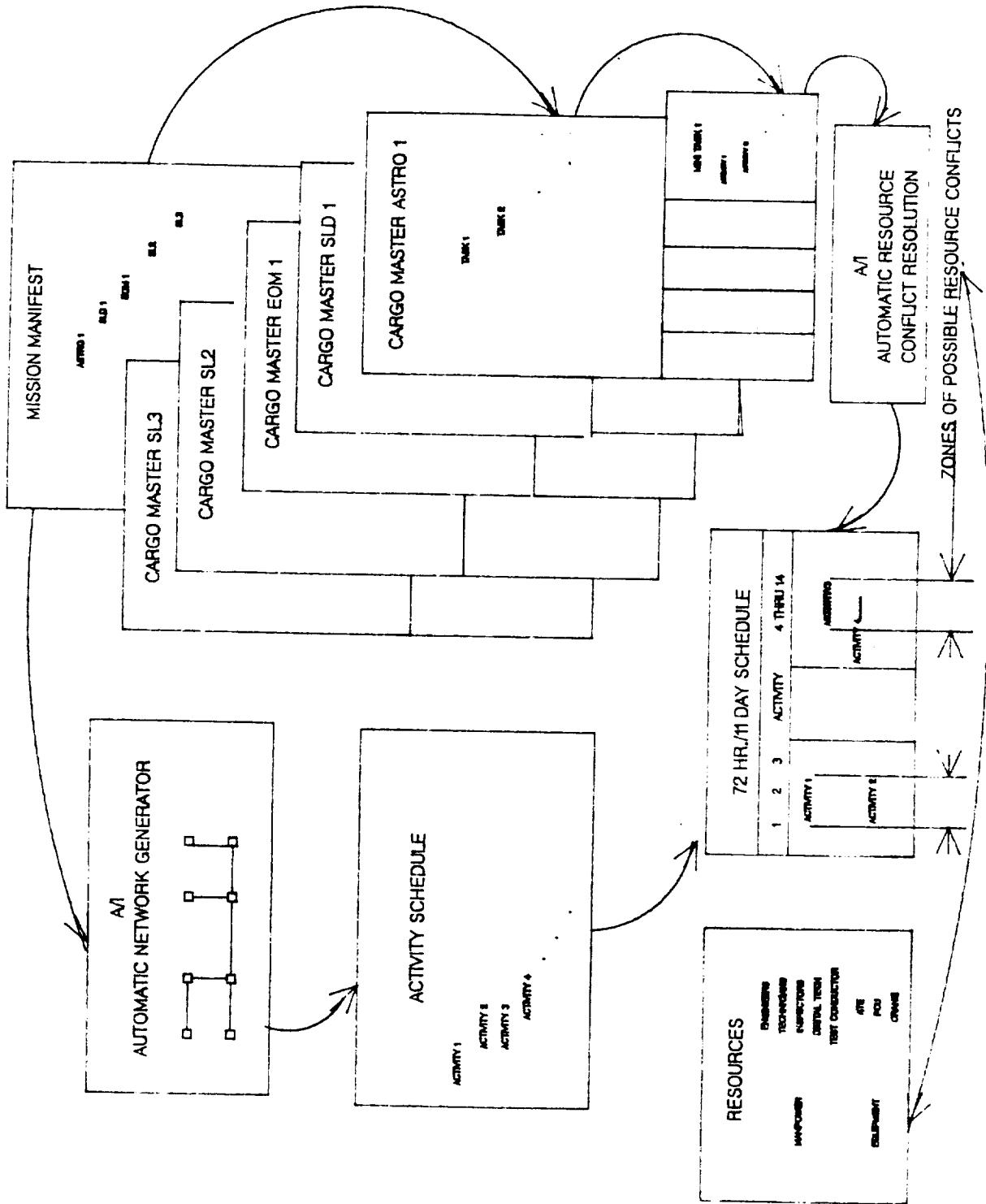
PROTOTYPE DEVELOPMENT: PERFORMED BY McDONNELL DOUGLAS TECHNICAL SERVICES THROUGH A SUB-CONTRACT WITH GEORGIA TECH ON SYMBOLICS 3600.

STATUS: FINAL PROTOTYPE WILL DEMONSTRATED ON MAY 22, 1985 AND A DECISION WILL BE MADE AT THAT POINT ON WHETHER TO CONTINUE TO MAKE THE APPLICATION OPERATIONAL.

An expert system called PLANET (Plan Network) is currently being developed by Georgia Tech under subcontract to MDTSO (McDonnell-Douglas Technical Services Co.) to assist in the development of cargo-processing schedules. The initial application will be to the detailed 72-Hour Schedule for Spacelab. Sub-schedules are currently developed manually and independently and then integrated, the conflicts being resolved by the human scheduling expert. It is this integration that is being automated. The work is being done using an expert system-building tool developed by Georgia Tech called GES (Generic Expert System Tool) and will be delivered on a Symbolics 3600.

Expert Planning System Details
Christy Wetzel & Jim Lounoulin
KSC

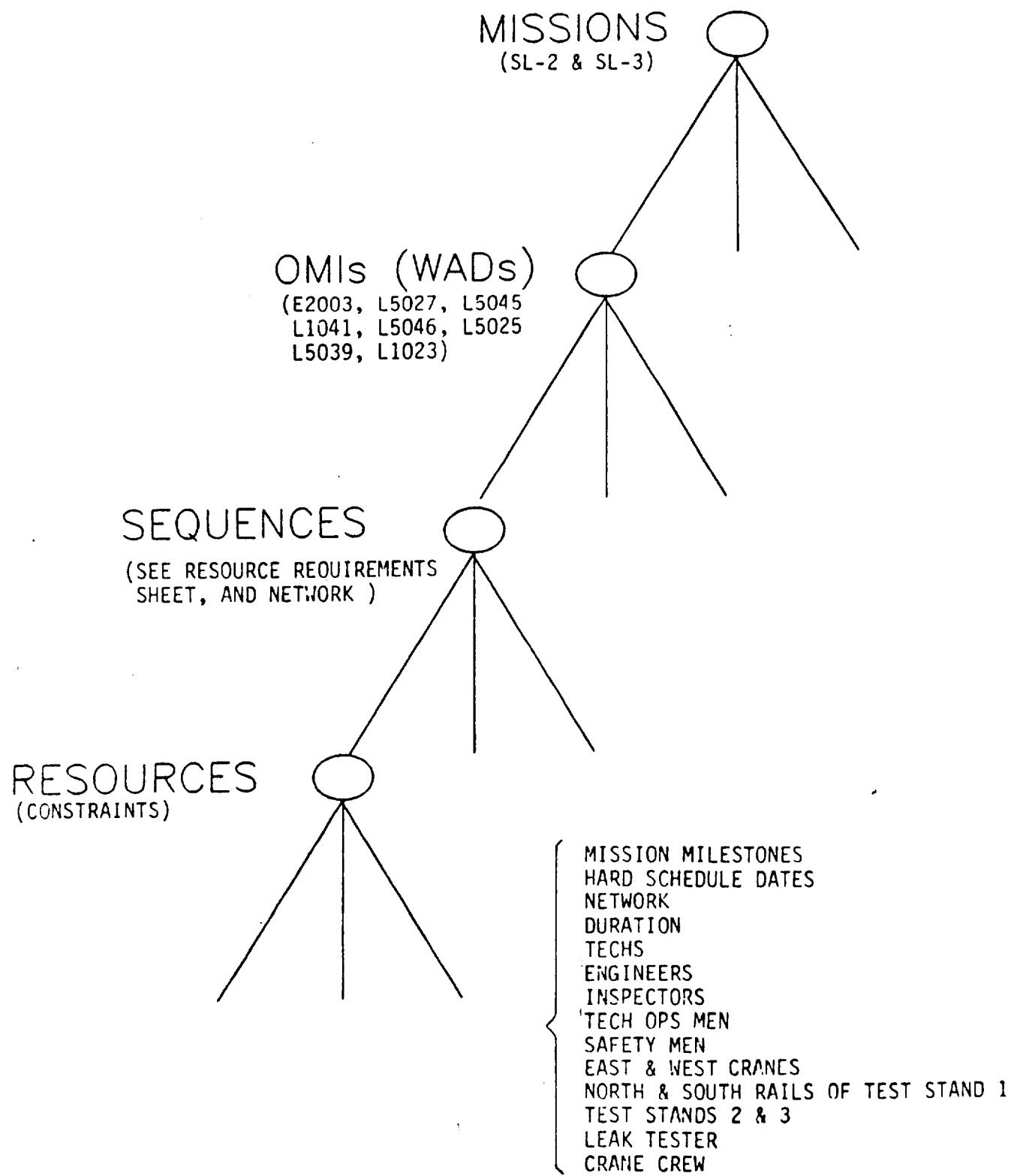
A/I APPLICATIONS



PLANNET

HIERARCHICAL DATA STRUCTURE

(DOMAIN DATA)



MDTSCO PLANNER

MISSION: SPACELAB-2...
...SPACELAB-3

Message Pane

FROM: 5/10/85 TO: 5/12/85

10 11 12

SEQUENCE

TO: 5/23/85 FROM: 5/13/85

13 14 15 16 17 18 19 20 21 22 23

10 11 12 13 14 15 16 17 18 19 20 21 22 23

Top

SPACELAB-2

PREP, MDTSCO
MAIN AND BRACE ROD ASSEMBLY PREPS
POSITION SUPPORT STRINGS
COUNTERWEIGHT THERMAL VERIFICATION
OPERATING INSTRUCTIONS, MAIN AND
STRONGBACK CONFIGURATION
WORK AREA AND EQUIPMENT PREPS
RECEIVING TEST STRUT PREPS
TRUNKING RETAINER INSTL.
STRONGBACK HOOKUP TRANSFER
ATTACH TO PAYLOAD
PROLOG RETRIEVE FROM TS TRANSFER
INSTALLATION INTO RDC TS
STRONGBACK REMOVAL & TRANSFER
PREPARATION
1Q100 COVER INSTALLATION PART 1
1G100 COVER INSTALLATION PART 2
LEP TEST EQUIPMENT CONFIGURATION
C-O-S ADAPTER ATTACH

More below

•

Top

TECH MEN

ENGINEERS

INSPECTORS

TECH OP MEN

SAFETY MEN

CREAM (R)

EDIE, FLIVABLE, TECH MEN

Operation: Increment Decrement Set to New Value

Amount: 0

Start Time: Fri. 5/10/85 00:00:00

Duration: never

Repeat every: never

End Time: Fri. 5/17/85 00:00:00

Exit

•

Bottom

TECH MEN

EDIT RESOURCE

EDIT RESOURCE

PRINT SCHEDULE

ALL SCHEDULES

FIRST FIT

SHOW ADVICE

SHOW ACTIONS

ONE DATA ENTRY

SET DATE

QUIT

Choose

85-10-85 14:59:22 GREEN

KSC
CARGO
OPERATIONS

PLANET SYSTEM DESIGN

Jim Dumoulin

MAY 1985

SPACELAB LEVEL III/II

72 HOUR / 11 DAY

SCHEDULING SYSTEM

PLANNET DEVELOPMENT TEAM

MDTSCO:

John Newcome
Ron Desplain
Stan Green

Project Manager 70%
Technical Manager Programming 100%

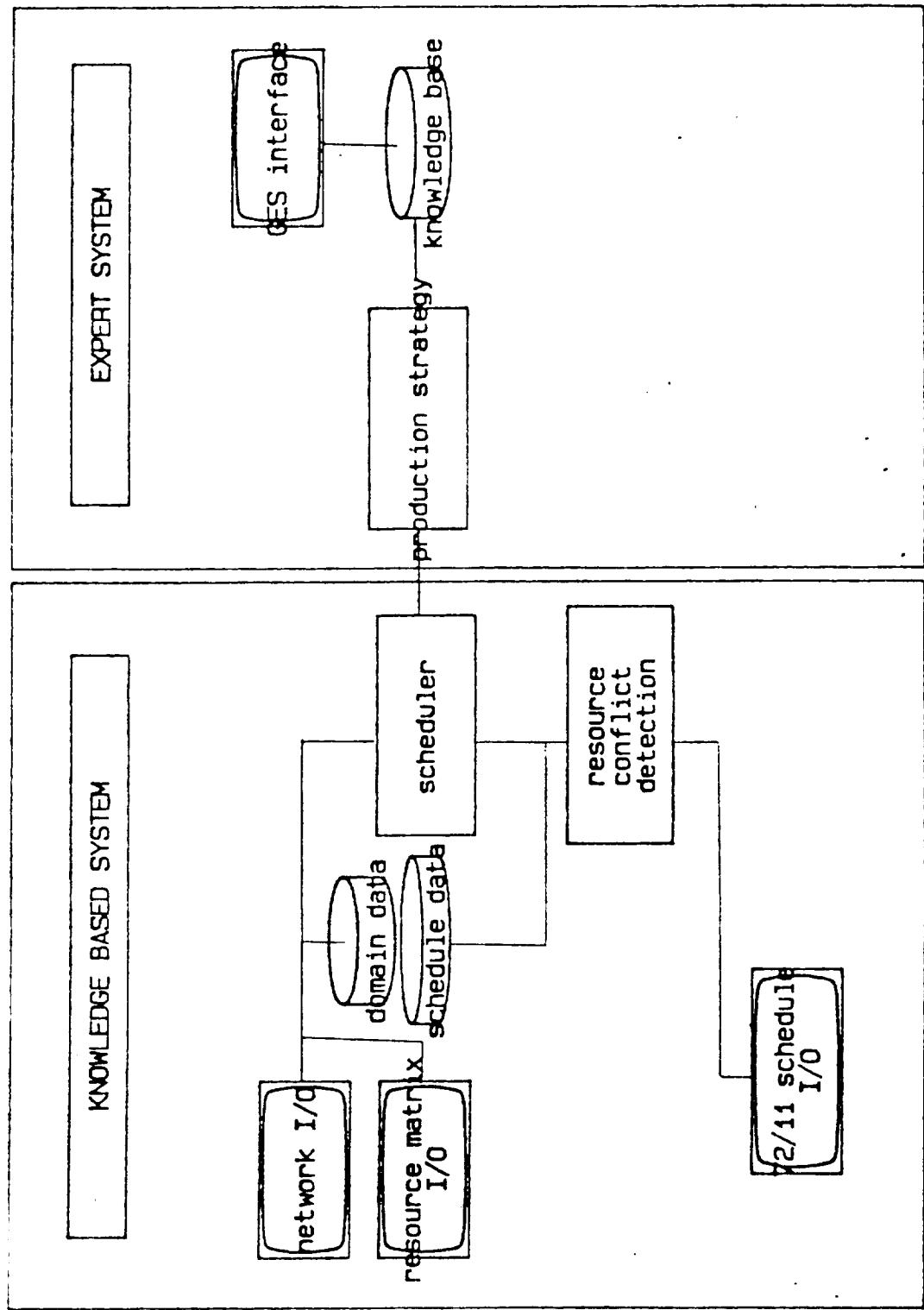
GTRI:

John Gillmore
Antonio Semeco
Pipat Eamsherangkoon
Dinh Vu

AI Expert / System Design 50%
Georgia Tech Grad Student 100%
Georgia Tech Grad Student 100%
Georgia Tech Undergraduate 100%

ZHACS (Text) slides3.text >downoutline text CALLISTO: (1) Font: D (TR12) * [More above]

PLANET SYSTEM ARCHITECTURE



PLANNER USER INTERFACE

The screen display of the PLANET system is broken up into 2 major parts. The top half is 72 Hour / 11 Day schedule like the ones currently generated daily at the Kennedy Space Center. They contain very detailed information about the work scheduled for the next 72 hours, and slightly less detail about the next 11 days. The lower pane shows histograms of resource usage for the above schedule. A scheduler has the following options:

DISPLAY

- Online Documentation
- Display OMIs (Documents that authorize work)
- Display Sequences (Steps in OMIs that perform work)
- Read in a Schedule from the file system
- Display the next conflict if any.
- Modify the time scale
- Set a Date to display
- Print out a Schedule

SCHÄDLIN

卷二

RILM

**ALL INTERFENCES
SHOULD INFERENCE
SHOW ACTION
SHOW ADVICE**

[Fire all rules on this Step](#) [View an Action Rule](#) [View an Advice Rule](#)

ZHFRCS (Text) slides8 -text >dunouin>text CALLISTO: (4) Font: F (CP1FONT) * [More above]

A SAMPLE SESSION WITH PLANNET

14:49:12

SCHEDULER SELECTS DATAFILES TO LOAD. FOR THIS SESSION SPACELAB-2 AND SPACELAB-3 WERE USED.

14:50:51

SCHEDULER SELECTS START AND STOP MILESTONES FOR LEVEL III/II PROCESSING OF THE CARGO. MILESTONES APPEAR AS RIGHT TRIANGLES ON THE DISPLAY.

14:51:33

SCHEDULER SELECTS DEFAULT RESOURCES TO USE. THESE RESOURCES DRIVE RESOURCE CONSTRAINTS. REQUESTS FOR RESOURCES GREATER THAN THIS DEFAULT WILL TRIGGER RESOURCE CONSTRAINTS AND AN ASTRISK WILL APPEAR BESIDE THAT RESOURCE.

14:54:43

A MOUSE CLICK ON ITEMS IN THE RESOURCE LIST WILL DISPLAY A HISTOGRAM OF THOSE RESOURCES. THE SOLID BAR AT THE TOP INDICATES THE DEFAULT RESOURCE LEVEL. SCHEDULE BARS ARE ALSO DRAWN DIFFERENTLY TO CONVEY RESOURCE OR TEMPORAL CONSTRAINT VIOLATIONS. IF A BAR IS HOLLOW ON TOP, A TEMPORAL VIOLATION OCCURRED, AND IF A BAR IS HOLLOW ON THE BOTTOM, A RESOURCE VIOLATION OCCURRED.

MDTSCO PLANNET
 FRAME 1: 72-HOUR/11-DAY SCHEDULE
 MISSION: SPACELAB-3

Message Pane

TO: 5/12/85

FROM: 5/12/85

TO: 5/23/85

SEQUENCE

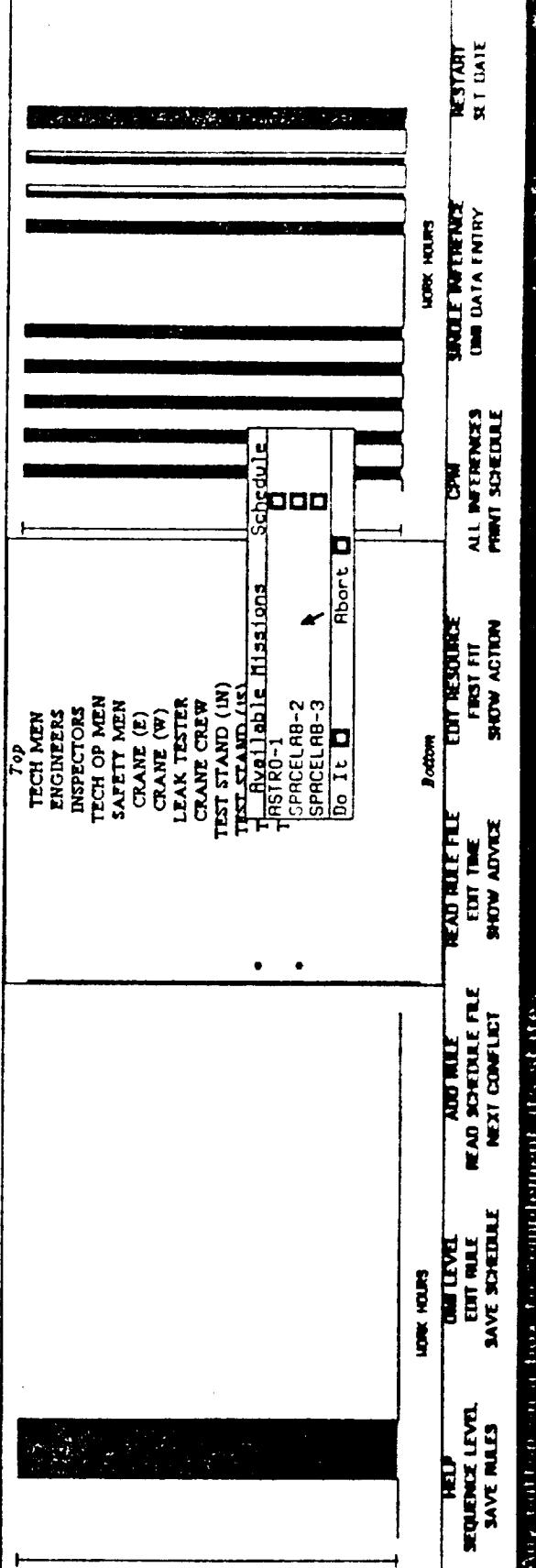
10 11 12

10 11 12

13 14 15 16 17 18 19 20 21 22 23

Top

SPACELAB-2
 PREPS, P10300
 MAIN AND INSTRUMENT ASSEMBLY PREPS A E2063
 POSITION SUPPORT STRINGS B E2063
 COUNTERWEIGHT TRAVEL VERIFICATION C E2063
 OPERATING INSTRUCTIONS, MAIN AND D E2063
 STRONGBACK CONFIGURATION E E2063
 WORK AREA AND EQUIPMENT PREPS F L3927
 RECEIVING TEST STAND PREPS G L3927
 RETRANSMITTER INSTL H L3927
 STRONGBACK HOODUP TRANSFER I L3927
 ATTACH TO PAYLOAD J L3927
 PAYLOAD REMOVAL FROM TS/LA TRANSFER K L3927
 INSTALLATION INTO ROV/C TS L L3927
 STRONGBACK REMOVAL & TRANSFER M L3927
 PREPARATION INSTALLATION PART 1 N L3943
 IGLOO COVER INSTALLATION PART 1 O L3943
 IGLOO COVER INSTALLATION PART 2 P L3943
 LEPK TEST EQUIPMENT CONFIGURATION Q L1841
 C-0-3 ADAPTER ATTACH R L1841
 More below



MDTSCO PLANNET
 FRAME 1: 72-HOUR/11-DAY SCHEDULE
 MISSION: SPACELAB-2...

Message Pane

TO: 5/12/85

FROM:	5/10/85	10	11	12	13	14	15	16	17	18	19	20	21	22	23
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From: [REDACTED] To: [REDACTED]

FROM:	5/13/85	TO:	5/13/85	SEQUENCE	13	14	15	16	17	18	19	20	21	22	23
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Top

SPACELAB-2
 PREPS., TOISSO
 MAIN AND BRACE AND ASSEMBLY PREPS
 POSITION SUPPORT STANDS
 COUNTER-EIGHT TRAVEL VERIFICATION
 OPERATING INSTRUCTIONS, MAIN AND
 STRONGBACK CONFIGURATION
 WORK AREA AND EQUIPMENT PREPS
 RECEIVING TEST STAND PREPS
 TRUNNION RETAINER INSTL
 STRONGBACK HOOKUP TRANSFER
 ATTACH TO PAYLOAD
 PAYLOAD REMOVAL FROM TSI TRANSFER
 INSTALLATION INTO IRUG TS
 STRONGBACK REMOVAL & TRANSFER
 PREPARATION
 1Q100 COVER INSTALLATION PART 1
 1Q100 COVER INSTALLATION PART 2
 LEAK TEST EQUIPMENT CONFIGURATION A L1841
 G-O-S ADAPTER ATTACH B L1841

More below

WORK HOURS	Top	Bottom
WORK HOURS	TECH MEN ENGINEERS INSPECTORS TECH OF MEN SAFETY MEN CRANE (E) CRANE (W) LEAK TESTER CRANE CREW TEST STAND (IN) TEST STAND (LS) TEST STAND (2) TEST STAND (3) WORK HOURS	CPM EDIT RESOURCE READ RESOURCE READ SCHEDULE FILE EDIT RULE SAVE SCHEDULE NEXT CONFLICT SHOW ADVISE FIRST FIT ALL PREFERENCES PRINT SCHEDULE DATA ENTRY SET DATE RESTART
WORK HOURS	Milestones for Mission SPACELAB-3 Mission Start Time: Fri. 5/18/85 00:00:00 Mission End Time: Fri. 5/27/85 00:00:00	Bottom
WORK HOURS	Exit <input type="checkbox"/>	Bottom

Choose : PLANNE

PLANNE

PLANNE

PLANNE

MDTSCO PLANNET

FRAME 1: 72-HOUR/11-DAY SCHEDULE
MISSION: SPACELAB-2...
...SPACELAB-3

FROM: 5/10/85 TO: 5/12/85 Message Pane

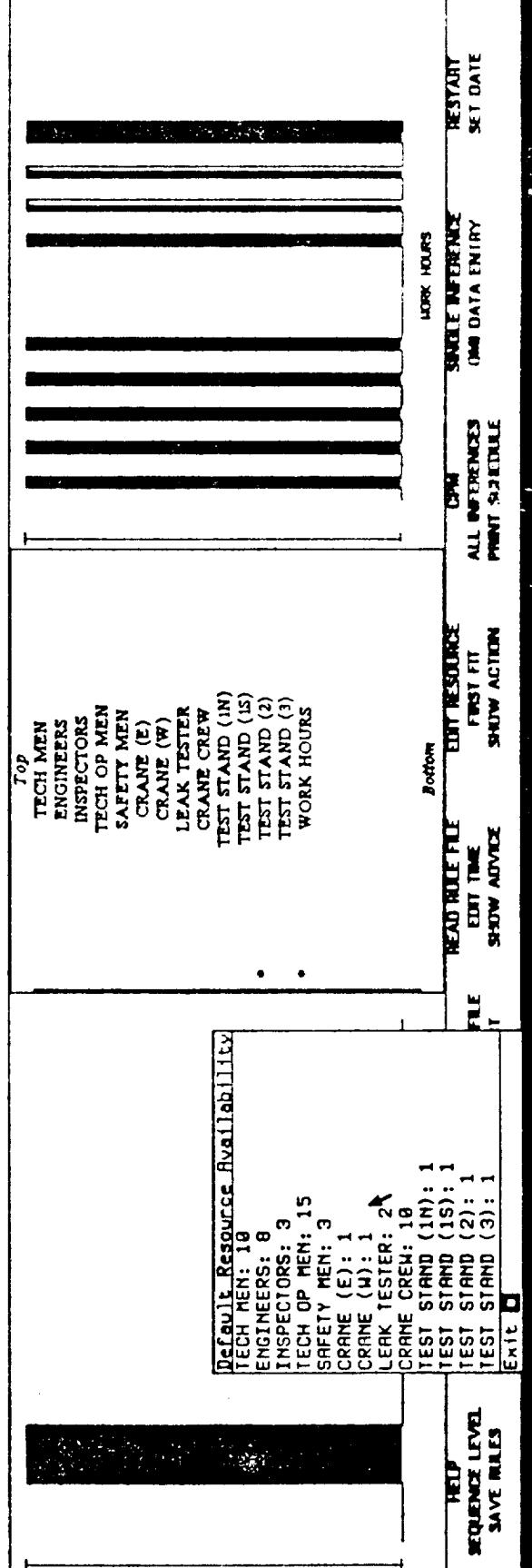
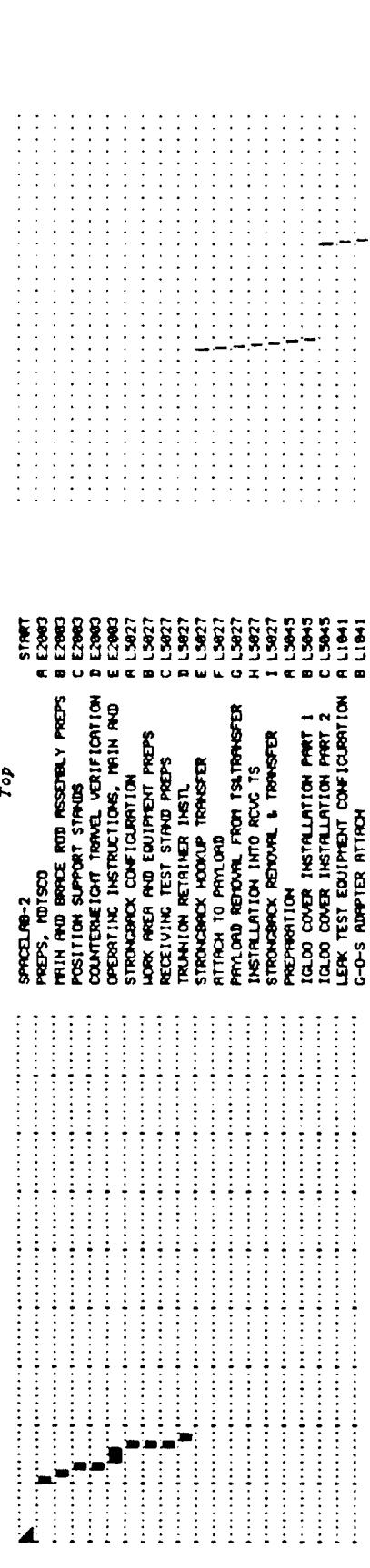
TO: 5/13/85

FROM: 5/13/85 TO: 5/23/85

TO: 5/23/85

SEQUENCE

10 11 12



MDTSCO PLANNET

FRAME #: 72-HOUR/11-DAY SCHEDULE
MISSION: SPACELAB-2...
...SPACELAB-3

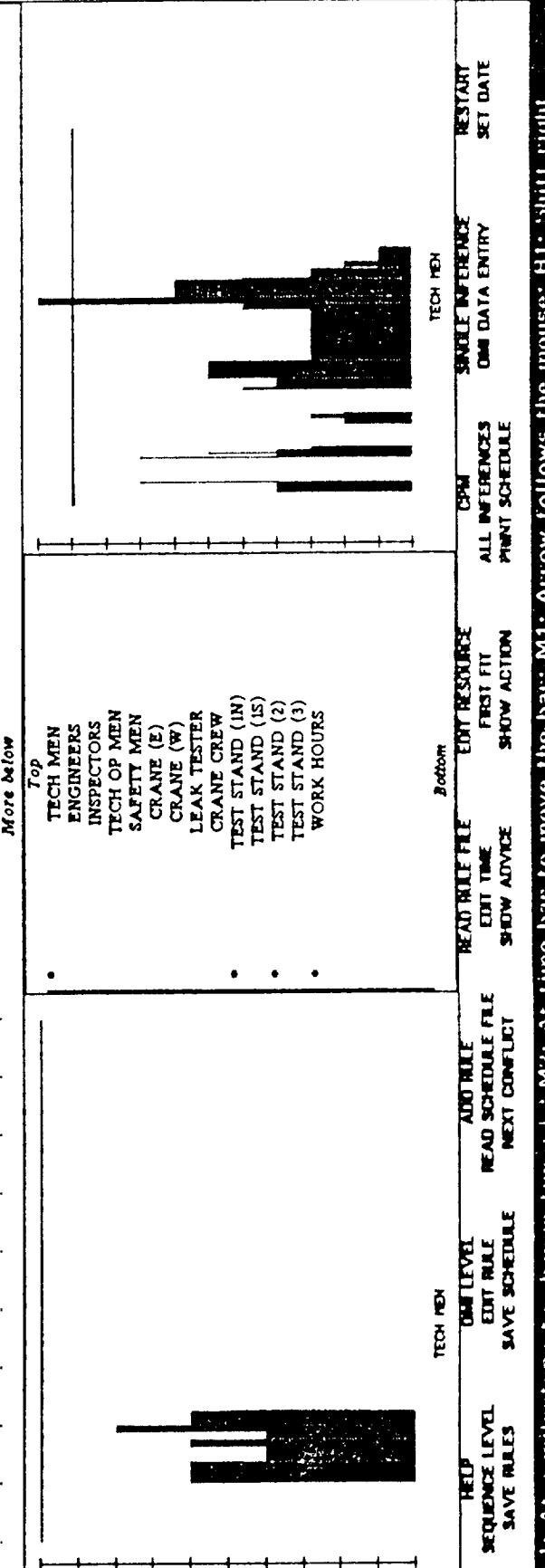
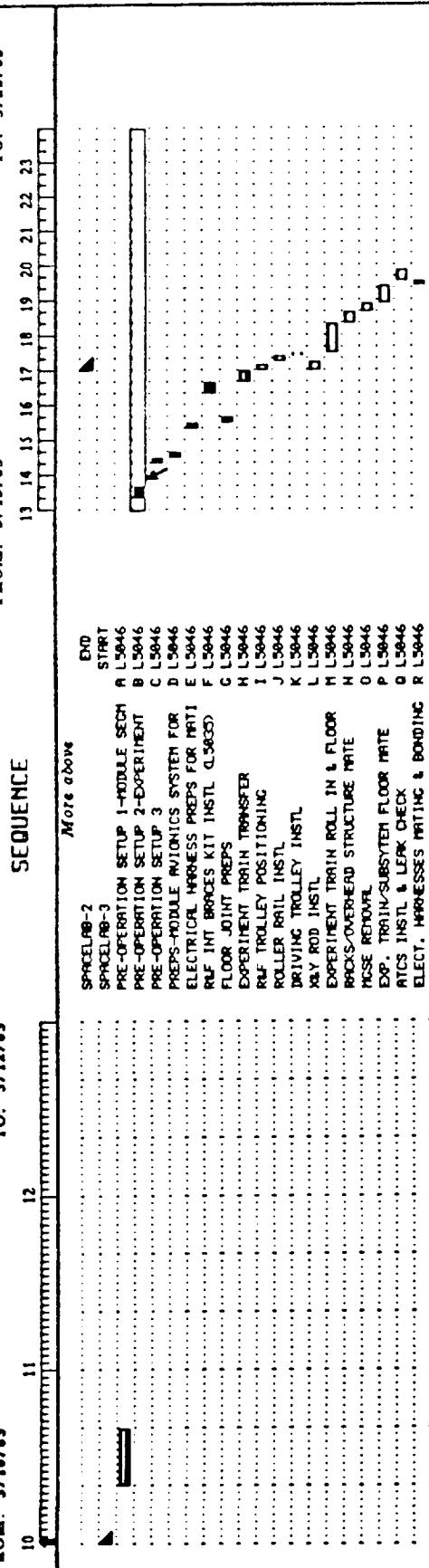
Message Pane

FROM: 5/18/85 TO: 5/22/85

10 11 12

FROM: 5/13/85 TO: 5/22/85

13 14 15 16 17 18 19 20 21 22 23



A SAMPLE SESSION WITH PLANNET

14:57:12

THE SCHEDULER LOOKS AT ONE OF THE RULES IN THE RULE BASE. THIS PARTICULAR RULE PRINTS A MESSAGE IF A CONFLICT IN THE SCHEDULE IS FOUND.

14:57:51

THE SCHEDULER LOOKS AT AN ACTION RULE THAT SAYS IF WORK IS SCHEDULED FOR 12 HOURS A DAY, SIX DAYS A WEEK, AND THE MILESTONE STILL CAN'T BE MET, THEN SCHEDULE AN 8 HOUR SHIFT ON SUNDAY AND RE-RUN THE SCHEDULE.

14:59:12

THE SCHEDULER DECIDES TO ADD MORE TECHNICIANS TO HELP ELIMINATE A RESOURCE CONFLICT. THAT PLANNET HAS FOUND.

14:59:22

A POPUP MENU APPEARS AND ALLOWS THE SCHEDULER TO EDIT THE DEFAULT RESOURCES. RESOURCES CAN BE ADDED OR SUBTRACTED ON A PER UNIT TIME BASIS.

MDTSCO PLANNET
 FRAME 1: 72-HOUR/11-DAY SCHEDULE
 MISSION: SPACELAB-2...

Message Pane

FROM: 5/10/85 TO: 5/12/85

FROM: 5/13/85 TO: 5/23/85

10 11 12

13 14 15 16 17 18 19 20 21 22 23

10 11 12

13 14 15 16 17 18 19 20 21 22 23

Top

Start

SPACELAB-2
 PROPS, MDTSCO
 MAIN AND BRACE ROD ASSEMBLY PREPS
 POSITION SUPPORT STRANDS
 COUNTERWEIGHT TRAVEL VERIFICATION
 OPERATING INSTRUCTIONS, MAIN AND
 STRONGBACK CONFIGURATION
 WORK AREA AND EQUIPMENT PREPS
 RECEIVING TEST STAND PREPS
 TRAINING RETAINER INSTL
 STRONGBACK MOCKUP TRANSFER
 ATTACH TO PAYLOAD
 PAYLOAD REMOVAL FROM TS4 TRANSFER
 INSTALLATION INTO R/C/T/S
 STRONGBACK RETRACTION & TRANSFER
 PREPARATION
 IGLDO COVER INSTALLATION PART 1
 IGLDO COVER INSTALLATION PART 2
 LEAK TEST EQUIPMENT CONFIGURATION
 C-O-S ADAPTER ATTACH

More below

Top

TECH MEN
 ENGINEERS
 INSPECTORS
 TECH OF MEN
 SAFETY MEN
 CRANE (E)
 CRANE (W)
 LEAK TESTER
 CRANE CREW
 TEST STAND (IN)
 TEST STAND (IS)
 TEST STAND (2)
 TEST STAND (3)

Edit Rule
 Rule Number: 10
 Class: ADVICE
 LHS: ((ANY-CONFLICT-P))
 RHS: ((GIVE-ADVICE "Advice: There are still conflicts in the schedule."))
 Function: NIL
 Index of rules in conflict: NIL
 Index of rules that it depends on: NIL
 Documentation: "Advice: Still Problems in the schedule."
 Date created: 5/06/85 16:41:26

Exit

Rule Number: 10
 Class: ADVICE
 LHS: ((ANY-CONFLICT-P))
 RHS: ((GIVE-ADVICE "Advice: There are still conflicts in the schedule."))
 Function: NIL
 Index of rules in conflict: NIL
 Index of rules that it depends on: NIL
 Documentation: "Advice: Still Problems in the schedule."
 Date created: 5/06/85 16:41:26

Exit

RESTART
 SINGLE INference
 DATA ENTRY
 SET DATE
 OPEN
 ALL INferences
 PRINT SCHEDULE

Choose
 PLANNER: 05/10/85 14:57:12 GREEN

MOTSCO PLANNER
 FRAME: 172+HOUR/11-DAY ONE SCHEDULE
 MISSION: SPACELAB-2...
 SPACELAB-3

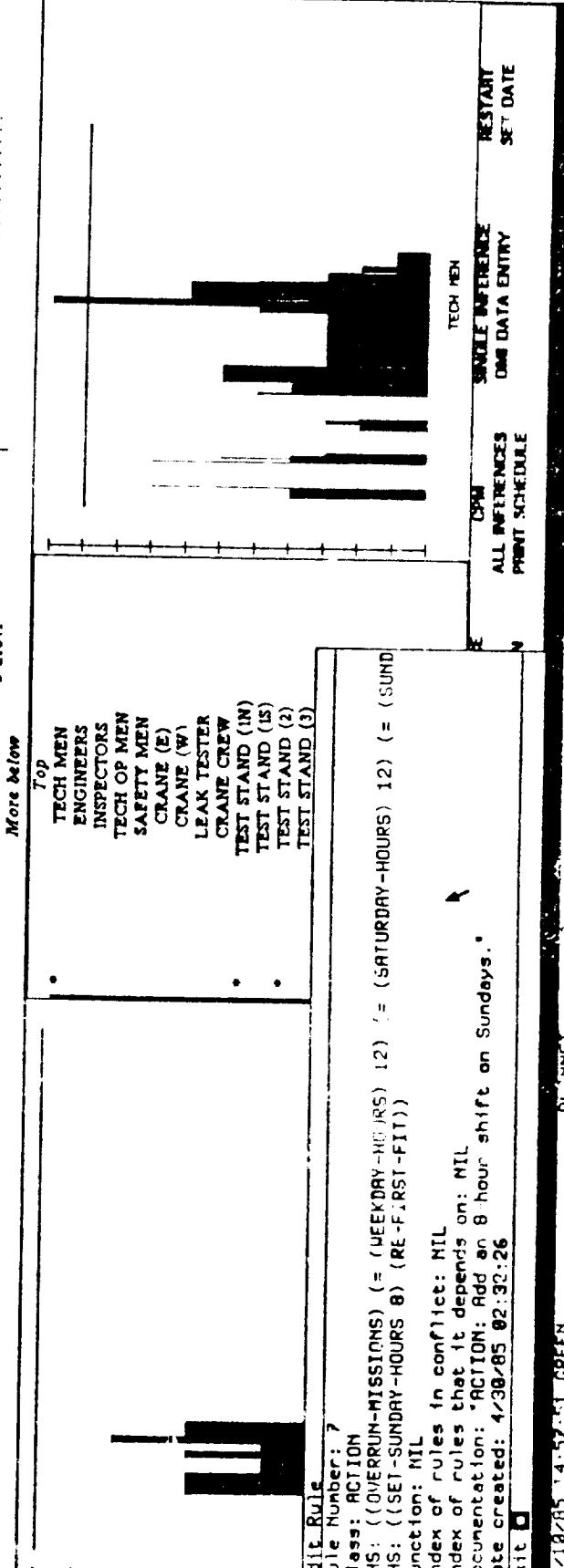
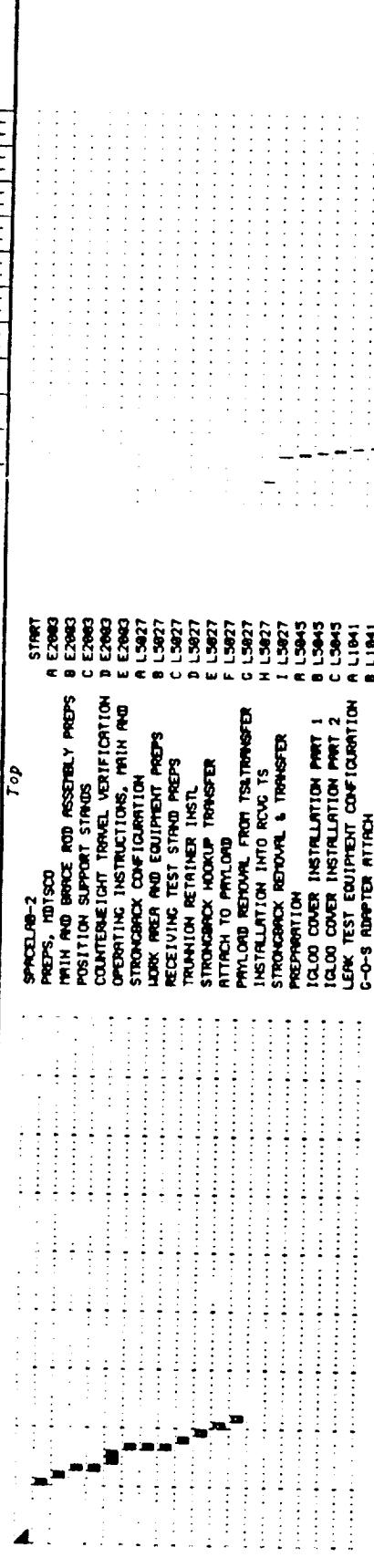
Message Pane

FROM: 5/10/85 TO: 5/12/85

SEQUENCE

FROM: 5/11/85 TO: 5/23/85

TO: 5/23/85



MDTSCO PLANNET
FRAME 1: 72-HOUR/11-DAY ONE SCHEDULE
MISSION: SPACELAB-2...
...SPACELAB-3

FROM: 5/18/85 TO: 5/12/85

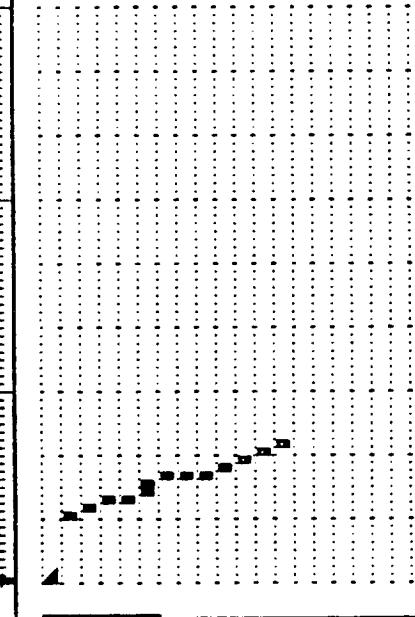
Message Pane

10 11 12

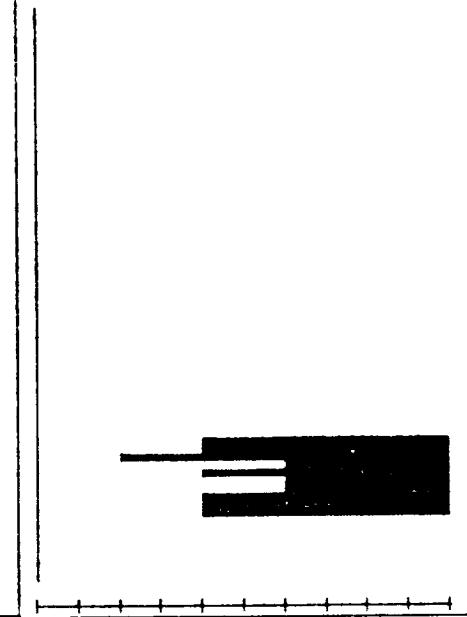
FROM: 5/13/85 TO: 5/23/85

SEQUENCE

13 14 15 16 17 18 19 20 21 22 23



More below



TECH MEN	UNIT LEVEL	ADD ROW FILE	READ ROW FILE	EDIT RESOURCE	OPM	SHOW INFERENCE	TECH MEN
HELP	EDIT RULE	READ SCHEDULE FILE	EDIT TIME	FIRST FIT	ALL INFERENCES	ONE DATA ENTRY	RESTART
SEQUENCE LEVEL	SAVE SCHEDULE	NEXT CONFLICT	SHOW ADVICE	SHOW ACTION	PRINT SOURCE	SET DATE	SET DATE
SAVE RULES							

PLANNET: Choose 05/18/85 14:59:22 GREEN

A SAMPLE SESSION WITH PLANNET

15:04:40 THE SCHEDULER RUNS ALL THE RULES ON THE AGENDA
 (THE ALL INFERENCES SELECTION) AND OBSERVES THE
 RULES AS THEY FIRE.

15:05:22 THE SCHEDULE IS RE-WORKED UNTIL ALL POSSIBLE
 RULES HAVE FIRED. BY THIS TIME, PLANNET HAS
 SCHEDULED WORK 24 HOURS PER DAY, 7 DAYS A WEEK.

15:07:51 PLANNET ADVISES SCHEDULER THAT THE MILESTONES ARE
 NOT VERY REALISTIC.

15:10:25 THE SCHEDULER SLIPS THE SPACELAB-2 MILESTONE (WHICH
 IS OFF THE SCREEN ON THE PRINTOUT) AND THE SCHEDULE
 IS RE-RUN. THE CONFLICTS GO AWAY.

MDTSCO PLANNET
 FRAME 1: 72+HR/11-DAY ONE SCHEDULE
 MISSION: SPACELAB-2...
 ...SPACELAB-2...

FROM: 5/10/85

Message Pane

TO: 5/12/85

SEQUENCE

10 11 12

FROM: 5/13/85

TO: 5/23/85

SEQUENCE

13 14 15 16 17 18 19 20 21 22 23

Top

START

SPACELAB-2

PREPS, MDTSCO

MAIN AND BRACE ROB ASSEMBLY PREPS

B E2083

POSITION SUPPORT STANDS

C E2083

COUNTERWEIGHT TURREL VERIFICATION

D E2083

OPERATING INSTRUCTIONS, MAIN AND

STRONGBACK CONFIGURATION

A L5927

WORK AREA AND EQUIPMENT PREPS

B L5927

RECEIVING TEST STAND PREPS

C L5927

TRANSPORT RETAINER INSTL

D L5927

STRONGBACK HOOKUP TRANSFER

E L5927

ATTACH TO PAYLOAD

F L5927

PAYLOAD REMOVAL FROM TS/TRANSFER

G L5927

INSTALLATION INTO RV/C TS

H L5927

STRONGBACK REMOVAL & TRANSFER

I L5927

PREPARED

A L5943

1600 COVER INSTALLATION PORT 1

B L5945

1600 COVER INSTALLED

C L5945

LEAK TEST EQUIP

D L5945

G-O-S ADAPTER ATT

RULE NUMBER: 8 fired.

IF (OVERRUN-MISSIONS)

AND (= (WEEKDAY-HOURS) 12)

AND (= (SATURDAY-HOURS) 12)

AND (= (SUNDAY-HOURS) 8)

THEN

(SET-SUNDAY-HOURS 12)

(RE-FIRST-FIT)

ACTION: Extend Sunday shift by 4 hours.

Inference Time: 5/10/85 15:04:13

RULE NUMBER: 9 fired.

IF (OVERRUN-MISSIONS)

AND (= (WEEKDAY-HOURS) 12)

AND (= (SATURDAY-HOURS) 12)

AND (= (SUNDAY-HOURS) 12)

THEN

(SET-WEEKDAY-HOURS 24)

(SET-SATURDAY-HOURS 24)

(SET-SUNDAY-HOURS 24)

(RE-FIRST-FIT)

ACTION: Enable 24 hours every day.

TECH MEN

READ RULE FILE

EDIT TIME

SHOW ADVIC

EXIT

PLANET:

Choose

PRESENCE

RESTART

ENTRY

SET DATE

REN

INFER

CONF

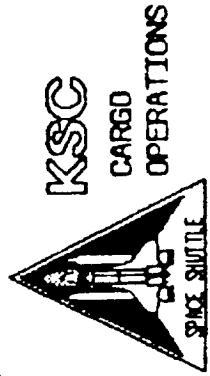
ADVICE

INFER

CONF

DIFFERENCES BETWEEN EXPRESS AND PLANMET

EXPRESS	PLANMET
Long Term Scheduling (years)	Short Term (72 Hr)
Accepts incomplete data	Data Must be Well Defined
Initial Input is from manifest	Input Is from OMI's
Variable Multi-level Resources	Fixed single level resources
System built from Scratch	Designed using GES (GA TECH)
	SIMILARITIES
	Both Written in LISP (ZETALISP) Both run on SYMBOLICS Lisp Machine Extensive use of Windows and Menus Histograms of Resource utilization



KSC
EMPRESS SOFTWARE DESIGN
PRESENTATION

JIM DUMOULIN

MAY 1985

EMPRESS

EXPERT MISSION PLANNING AND REPLANNING SCHEDULING SYSTEM

An expert system called EMPRESS is being developed jointly by KSC and MITRE as a prototype cargo-scheduling system. The driving input is the manifest for each Shuttle flight that is received from NASA/HQ in electronic form via TELEMAIL. Development is being done on a Symbolics 3600 using LISP and FLAVORS. Completion is projected for September 1985.

NASA

KENNEDY SPACE CENTER

EMPRESS DEVELOPMENT TEAM

NASA: (Level of Effort 1.5 Man Persons)

Dr. James Repusa	NASA Project Manager
Fred Heed	NASA Technical Manager
Jim Dumoulin	Programmer 100%
Vicki Lucas	KSC Scheduling Engineer 40%
Eric Schaefer	Programmer 10%

MITRE: (Level of Effort 1.5 Man Persons)

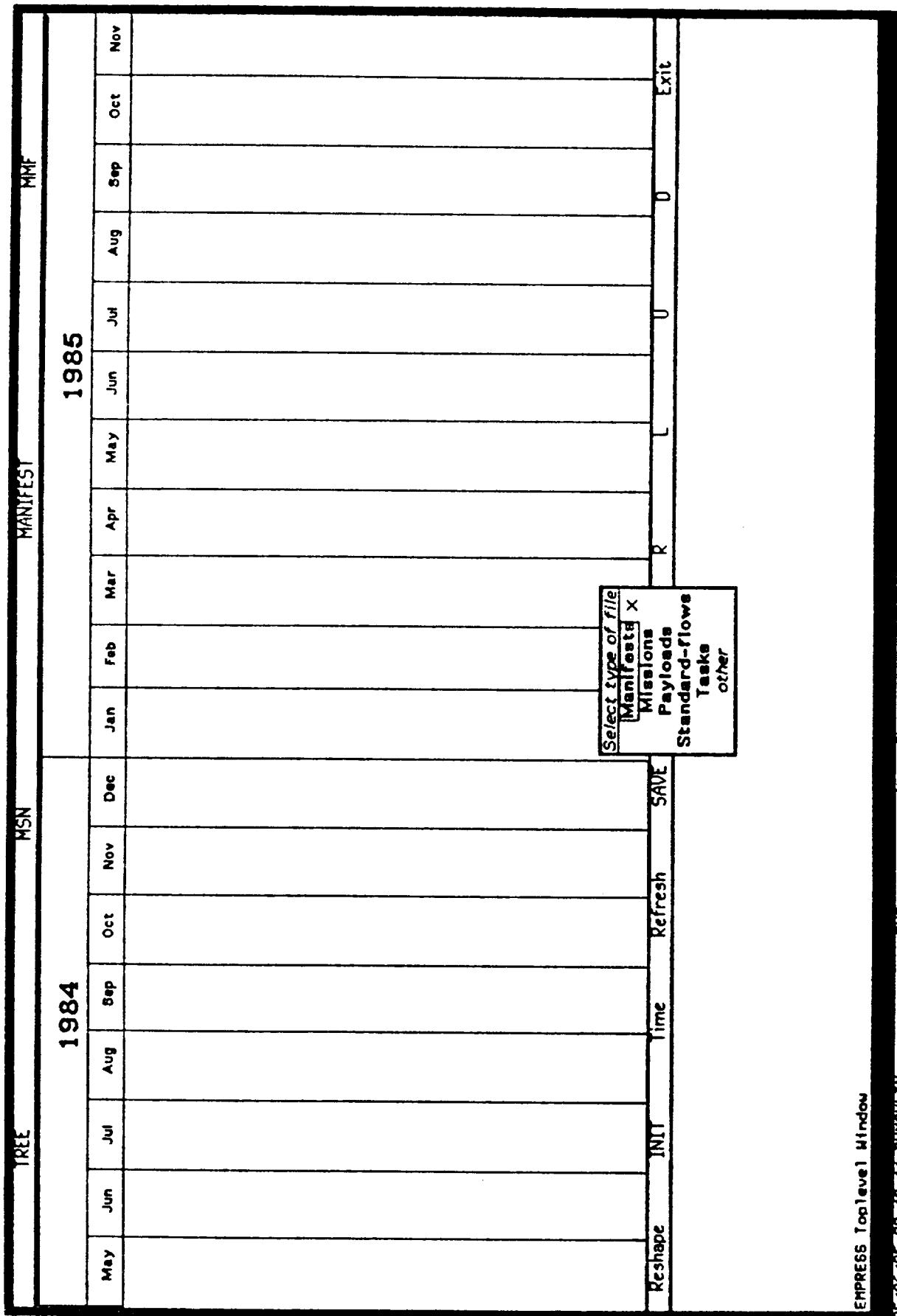
Dr. Joe Katz	MITRE Project Manager
Blair Hawkins	System Design/Programming 20%
John Jordan	Programmer 100%
Dr. Alice Mulvehill	Knowledge Representation 30%
Dr. Richard Brown	MITRE AI Expert/Consultant

ZINACCS (Text) \$1ideas3.text > DUMDOLINText CALLISTO: (3) Font: D (TR12) : [More above and below]

KSC's GOALS for the EMPRESS PROJECT

- 1.** Build an In House AI Capability
 - a) Train Civil Service Engineers in AI techniques
 - b) Setup the Hardware resources necessary to support AI Projects
 - c) Develop software tools that can be applied to other projects
 - d) Take an active role in the design of an Expert System.

- 2.** Design a Prototype Cargo Scheduling System
 - a) Must attack a part of the current scheduling problem and solve it at least as well as the status quo.
 - b) Must then be able to go beyond that



EMPRESS USER INTERACTION

When EMPRESS is first activated, a Blank Schedule Frame is displayed on the Computer Console. Many areas of the Screen are Mouse Sensitive. The scheduler just clicks the Mouse on one of the Mouse Sensitive Areas to perform an action.

The following are some of the Mouse Selections:

READ	Reads a Schedule into EMPRESS.
SAVE	Saves a Modified Schedule
INIT	Reinitializes Knowledge Base
REFRESH	Redisplays Current Context
RESHAPE	Allows Access to other EMPRESS Windows
TIME	Sets Display's Start and Stop Times
EXIT	Exits EMPRESS
R L U D	Moves Screen Right, Left, Up or Down
MANIFEST	Displays Currently Loaded Manifest
MSN	Selects Particular Missions in Manifest
MMF	Displays the Multi-Master Flow
TREE	Displays a Task and all its Sub-tasks

NOTE: These are Options that are ALWAYS available. Other options are available if RESHAPE is used to switch EMPRESS to other Configurations.

ZMACS (Text) &ides5.text >DUOULINtext CALLISTO: Font: D (TR12) * [More above]

HOW EMPRESS GETS SCHEDULE INFORMATION

When a user clicks the mouse on the READ menu, various other menus are displayed. These menus display the files that currently reside in the Empress Data Directory. They can be of various types.

MANIFESTS

Manifests that Empress knows about.

By convention, these files contain only information from the NASA Headquarters Shuttle Flight Baseline and technically can be created via electronic transfer from HQ.

MISSIONS

Files containing individual missions that a scheduler has added information not found in the baseline manifest. These files allow EMPESS to store schedule information that is particular to single mission.

PAYOUTS

Files that contain detailed processing schedules for individual payloads. These are just user enhanced copies of the Default Schedule that EMPESS creates.

STANDARD FLOWS

These files are schedule templates that contain knowledge learned from previous payloads that have used the same carrier configuration.

- **NOTE: UNLESS THE INIT OPTION HAS BEEN SELECTED, THESE FILES ARE LOADED IN ADDITION TO SCHEDULES EMPRESS ALREADY HAS LOADED**

ZHRCS (Text) slides6.text > DUMOULIN>text CALLISTO: (1) Font: E (TR12B) * [More above]

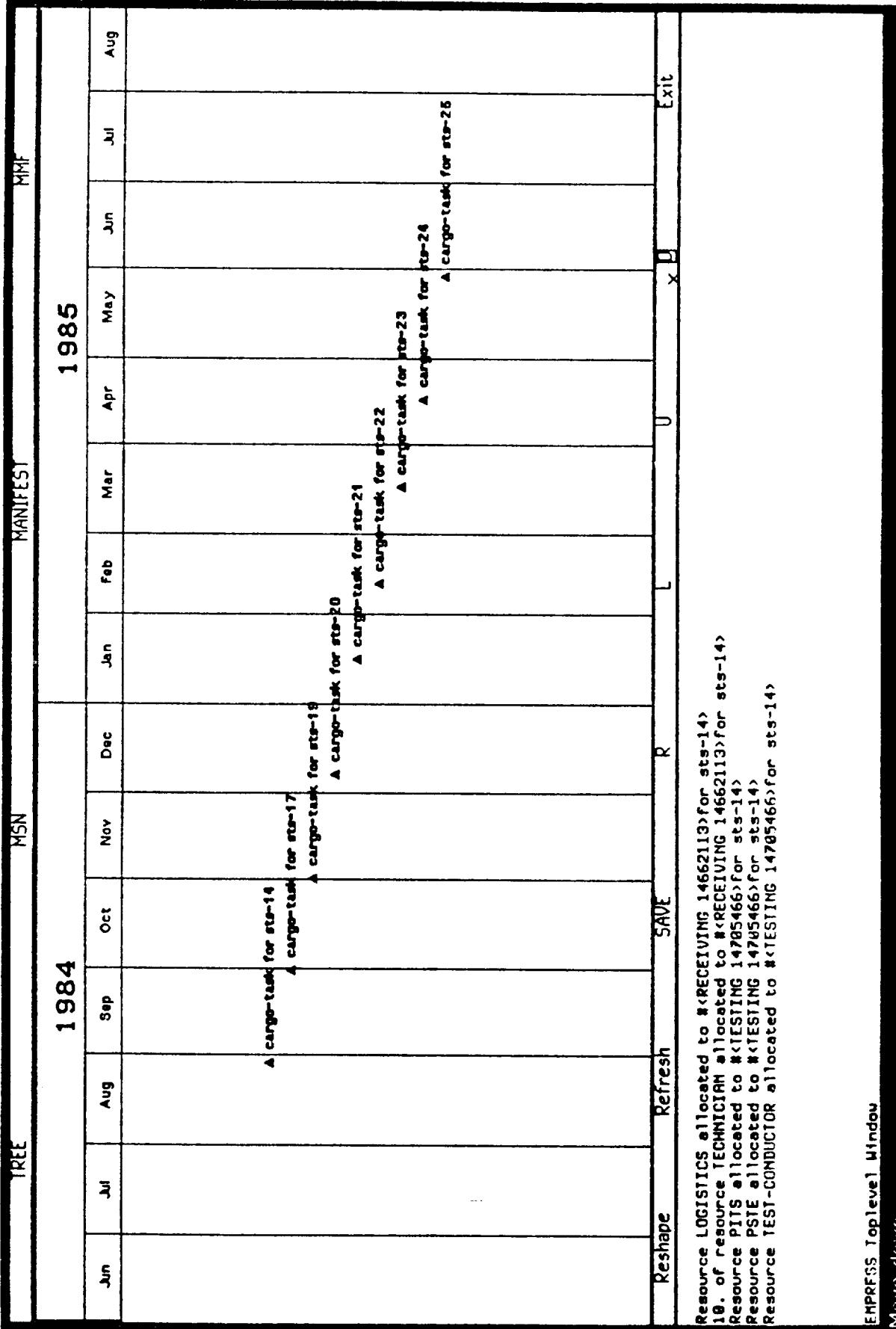
INPUT FILE FORMAT FROM NASA HEADQUARTERS
 (Transferred via Telenet to the Symbolics as a Text file)

*** SHUTTLE FLIGHT ASSIGNMENTS FOR PAYLOADS ***

PRELIMINARY MAY 1985 BASELINE

MSSN	DATE	INCL	CRW	PAYOUT	CARRIER	OTHER	UF	PAYOUTS
51-G	85 6 12	28.5	7	SPARTAN-1	MPRESS	FEE	[0.94W]	
25	DISCOVERY	190	7	MORELOS-A	PAM-D	FPE		
				ARABSAT-1B	PAM-D	ADSF		
				TELSTAR 3-D	PAM-D	HPTE		
						GAS(6)		
51-F	85 7 12	50.0	7	SPACELAB 2	IG+3P	SAREX	[1.00D]	
26	CHALLENGER	282	7					
51-I	85 8 10	28.5	7	MSL - 2	MPRESS	CFES III	[0.98W]	
27	DISCOVERY	190	5	RUSSAT - 1	PAM-D	FDE		
				ASC- 1	PAM-D	PUTOS		
				SYNCOM IV-4	IBSE			
					SSIP(2)			
51-J	85 9 26	0.0	0	DOD			[1.00D]	
28	ATLANTIS	0	0					
61-R	85 10 16	57.0	0	SPACELAB D-1	LM		[1.00L]	
29	COLUMBIA	175	7					
61-B	85 11 0	28.5	7	EDS-1		UNDER	[0.96W]	
30	CHALLENGER	190	5	MORELOS-B	PAM-D	REVIEW		
				SATCOM KU-1	PAM-D2	GAS(4)		
				AUSSAT - 2	PAM-D			

ZMACS (Text) manifest.text >press>paper CALLISTO: (2) Font: E * [More above]



INPUT FILE FORMAT TO PRODUCE MISSIONS

(Created either by the user from a text editor or created by
EMPESS from Mass driven Inputs to the Schedule Window)

```
(:mission
  :name "sts-14"
  :date-of-manifest "8-84"
  :flight-number "41-D"
  :sts-number 14
  :orbiter-vehicle discovery
  :launch-date "8-30-84"
  :stated-payloads (( "DASTI-1" "MPESS") ("LFC-1" "MPESS")
    ( "SBS-D" "PAM-D") ( "TELSTAR-3-C" "PAM-D")
    (CFES-III n11) (IMAX n11) (RME n11))
  :mission-duration 6)
```

ZMRC5 (Text) SLIDES2.TEXT >duoulin>text CALLISTO: Font: A (CPTFONT) * [More above]

EMPRESS PROGRAM STRUCTURE

The EMPRESS system is actually a collection of over 40 different LISP programs that interact together. They are organized into 5 major subsystems using the Symbolics DEFSYSTEM command. The systems are:

DM The Display Manager is responsible for all interaction with the user. It can be used to query the database with "What-If" type questions, and can display histograms of resource utilizations.

SM The Schedule Manager is responsible for building the Default Schedules, and reworking the current schedule when the Constraint Manager or Resource Manager flag an error.

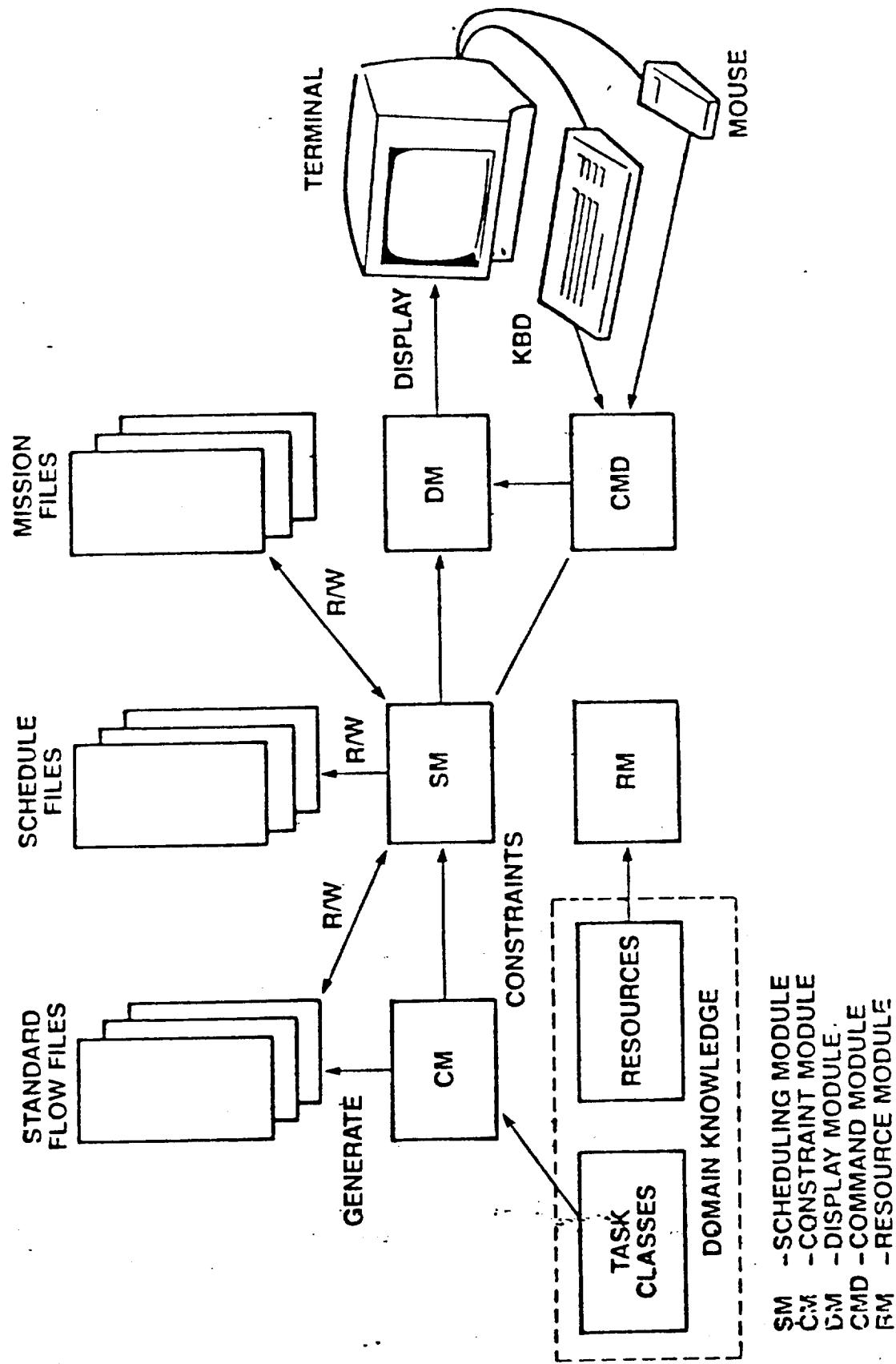
CM The Constraint Manager keeps track of the relationships between tasks. It is basically a watchdog on the SM.

RM The Resource Manager is a Quartermaster responsible for all Resources in the system. It also handles queries into the database and suggests alternatives when conflicts arise.

RULE This is a basic forward chaining inference engine that can be called by any of the other systems.

ZMACS (Text) \$ides8.text >dumoulin;text CALLISTO: (3) Font: D (TR12) [More above]
Written: CALLISTO:DUMOULIN;text\$ides8.text

EMPRESS Software Structure



EMPRESS INTERNAL DATA STRUCTURES

Internally, almost all data in the Empress system is stored as FLAVORS. Flavors are Objects that can be built up from other objects and they inherit all the knowledge and abilities of the objects from which they are built. These objects can understand messages that tell them when to perform certain operations.

Schedules in the EMPRESS system are ordered collections of TASKS. Each Task is an instance of a FLAVOR and can be composed of any number of other tasks. All Resources in the EMPRESS system are built on Flavors as well, and the Inference Engine operates by pattern matching the responses flavors return when sent messages.

There are many ways information can be organized and accessed in AI systems, and FLAVORS were picked because they provide a powerful mechanism for storing, organizing, and utilizing information.

TREE		MANIFEST																																														
		1985																																														
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan																						
Reshape	INIT	Time	Refresh	Time	Save	Read	Time	Refresh	Time	Save	Read	Time	Refresh	Time	Save	Read	Time	Refresh	Time	Save	Read	Time	Refresh	Time	Save	Read																						
<INTEGRATION 16231515> for sts-25																																																
An instance of INTEGRATION. &{Message handler for INTEGRATION,																																																
PRED-RELS:	&{AFTER (&{STAGING 16230761} for sts-25) GENERIC)																																															
CREATOR:	&{DURQUIN}																																															
ID:	&{SPACELAB.1.3}																																															
TASK-NAME:	'experiment-integration'																																															
TYPE:	INTEGRATION																																															
MILESTONES:	NIL																																															
START-TIME:	1/10/85 00:00:00																																															
END-TIME:	3/08/85 00:00:00																																															
PREDECESSORS:	&{INTEGRATION 16231274} for sts-25, &{STAGING 16230761} for sts-25)																																															
SUCCESSORS:	NIL																																															
FIRST:	&{INSTALLATION 16232030} for sts-25, &{TESTING 16231773} for sts-25, &{CONTINGENCY 16231736} for sts-25, &{CLOSEOUT 162																																															
LAST:	&{INSTALLATION 16232030} for sts-25, &{TESTING 16231773} for sts-25, &{CONTINGENCY 16231736} for sts-25, &{CLOSEOUT 162																																															
AFTER:	(*...*press/tsf-staging*)																																															
PARENT:	&{LEVEL-IV 16230724} for sts-25																																															
SUB-TASKS:	&{INSTALLATION 16231552} for sts-25, &{TESTING 16231607} for sts-25, &{CONTINGENCY 16231644} for sts-25, &{CLOSEOUT 162																																															
TIME-REQUIRED:	57																																															
UNITS:	DAYS																																															
EFFORT:	NIL																																															
SCHEDULE-LIST:	NIL																																															
CONSTRAINTS:	&{AFTER (&{STAGING 16230761} for sts-25) STD-FLOW) AFTER (&{TESTING 16231274} for sts-25) STD-FLOW) (CONTAINED-BY																																															
VIOLATION:	NIL																																															
RESOURCES:	NIL																																															
DISPLAY-ITEM:	&{ITEM 16338223}, unbound																																															
APPROVED:	unbound																																															
VALIDATED:	unbound																																															
SCHEDULED:	unbound																																															
LEADER:	unbound																																															
More Below																																																
2 of resource ELECTRICAL-ENGINEER allocated to &{CLOSEOUT 16231701} for sts-25, 4 of resource TECHNICIAN allocated to &{TESTING 16231773} for sts-25, Resource SAFETY allocated to &{TESTING 16231773} for sts-25, Resource CRANE allocated to &{TESTING 16231773} for sts-25, 2 of resource MECHANICAL-ENGINEER allocated to &{TESTING 16231773} for sts-25, 4 of resource TECHNICIAN allocated to &{TESTING 16231773} for sts-25, EMPRESS TopLevel Window																																																
85-03-08 21:35:32 DURQUIN JEFFREY ERN: Buffer Empty																																																

INPUT FILE FORMAT TO PRODUCE TASKS

(Created either by the user from a text editor or created by
EMPRESS from Menu driven Inputs to the Schedule Window)

```
(:task
  :task-name "experiment-integration"
  :type integration
  :parent "Level-IV"
  :time-required 57
  :units days
  :constraints nil
  :after ('pre-experiment-integration' "process//tsf-steering")
  :resources nil
)

(:task
  :task-name "experiment/npe-installation"
  :type installation
  :parent "experiment-integration"
  :time-required 39
  :units days
  :constraints nil
  :after n1
  :resources ((TECHNICIAN @ 38 2)
              (quality-control @ 38 1)
              (mechanical-engineer @ 38 3)
              (electrical-engineer @ 38 2))
)
```

ZHACS (Text) slides.text > dmenu>text CALLISTO: Font: E (TR12B) * [More above and below]

TREE

MSN

MANIFEST

1984

1985

1988

MMF

MANIFEST

1988

Nov

Dec

Jan

Feb

Mar

Apr

May

Jun

Jul

Aug

Sep

Oct

Nov

Dec

Jan

Inspection

-atmne requirements-(if-required)

-prep-for-integration

-experiment/integration

-system-functional-testing

-power-on-contingency

-closeout

-contingency

-wr-2-cg

-install-in-canistr

-Level-1

More above

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Select Line to display
 Start Time: 11/01/84 00:00:00
 End Time: 1/31/86 00:00:00
 Exit

Reshape INIT Time Refresh SAVE READ

Exit

More above

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HOW EMPRESS BUILDS A DEFAULT SCHEDULE

When EMPRESS loads a manifest, it looks to see if a detailed schedule already exists for individual missions in the manifest. If such a schedule exists, and if it was built under the same assumptions (i.e. it has the same payloads) as the manifest being loaded, it is used in the default schedule. For newly manifested missions, or modified missions, EMPRESS looks at each payload on the mission and sees if a detailed schedule exists for that Payload. Once more, if a detailed schedule exists, it is included. If a suitable match cannot be found, EMPRESS looks at the carrier configuration (MPRESS, LONG-MODULE, PAM-D etc) and will build a default schedule based on the previous history KSC has learned about payloads of a particular type.

The carrier configuration is the most detailed bit of information that EMPRESS can get from the baseline manifest. The carrier drives High-Bay floor space requirements, testing requirements, manpower estimates, etc.

NOTE: By its very nature, long range planning is incomplete. EMPRESS attempts to do as good as a current KSC scheduler could do given the same information. It will not fall apart when given incomplete information on a mission, or a carrier configuration that it has never seen.

TREE

MSN

MANIFEST

MMF

1984

1985

1984												1985											
May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	

Exit

D

U

A

READ

Reshape INIT Time Refresh SAVE READ

Exit

D

U

A

Reshape INIT Time Refresh SAVE READ

Creating Flavor instance #<PAYLOAD-CARRIER 16634644>
 Creating Flavor instance #<PAYLOAD-CARRIER 16634652>
 BUILDING A DEFAULT SCHEDULE FOR ats-25
 Successfully performed SET-START-TIME to 4/30/85 00:00:00 in <EVENT 17015731> on dock at 4/30/85 00:00:00
 Successfully performed SET-START-TIME to 8/10/85 00:00:00 in <EVENT 17015716> transcan at 8/10/85 00:00:00

Creating Flavor instance #<MISSION 16634531> for gts-25
 Creating Flavor instance #<PAYLOAD-CARRIER 16634630>
 Creating Flavor instance #<PAYLOAD-CARRIER 16634636>

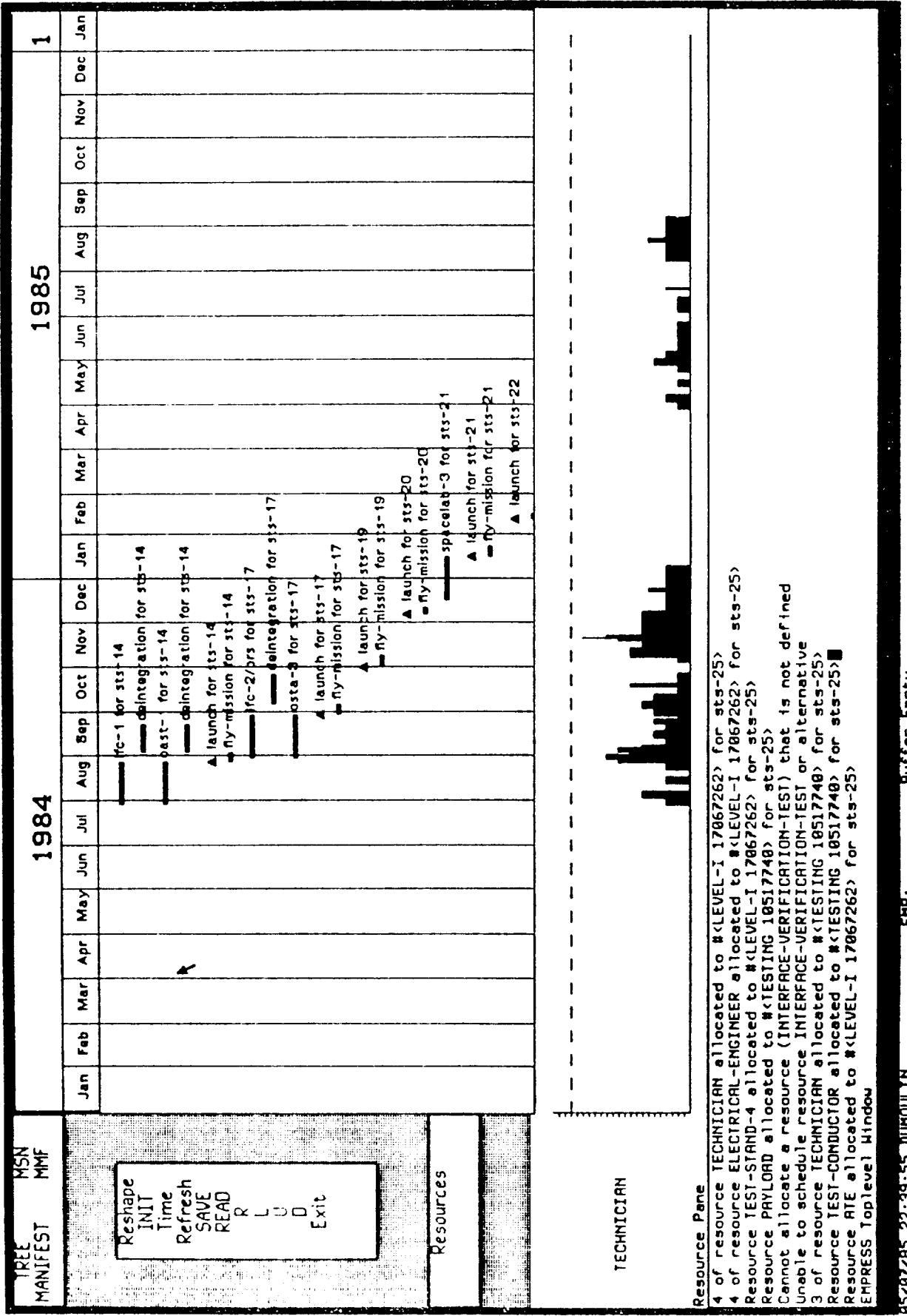
EMPRESS TopLevel Window

85-06/85 09:51:50 DUMOULIN EMPRESS

Run

RESOURCE TRACKING / MANAGEMENT

- o Flavor-Based Resource Hierarchy
- o Resource Characterization
- o Resource Allocation and Tracking
- o Resource Conflict Resolution



TREE
MANIFEST

MSN
MMF

1984

Reshape
INIT
Time
Refresh
SAVE
READ
R
L
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D
Exit

Resources

More above

STS-SUBSYSTEM-HARDWARE
CABLE-HARNESS
CABLE

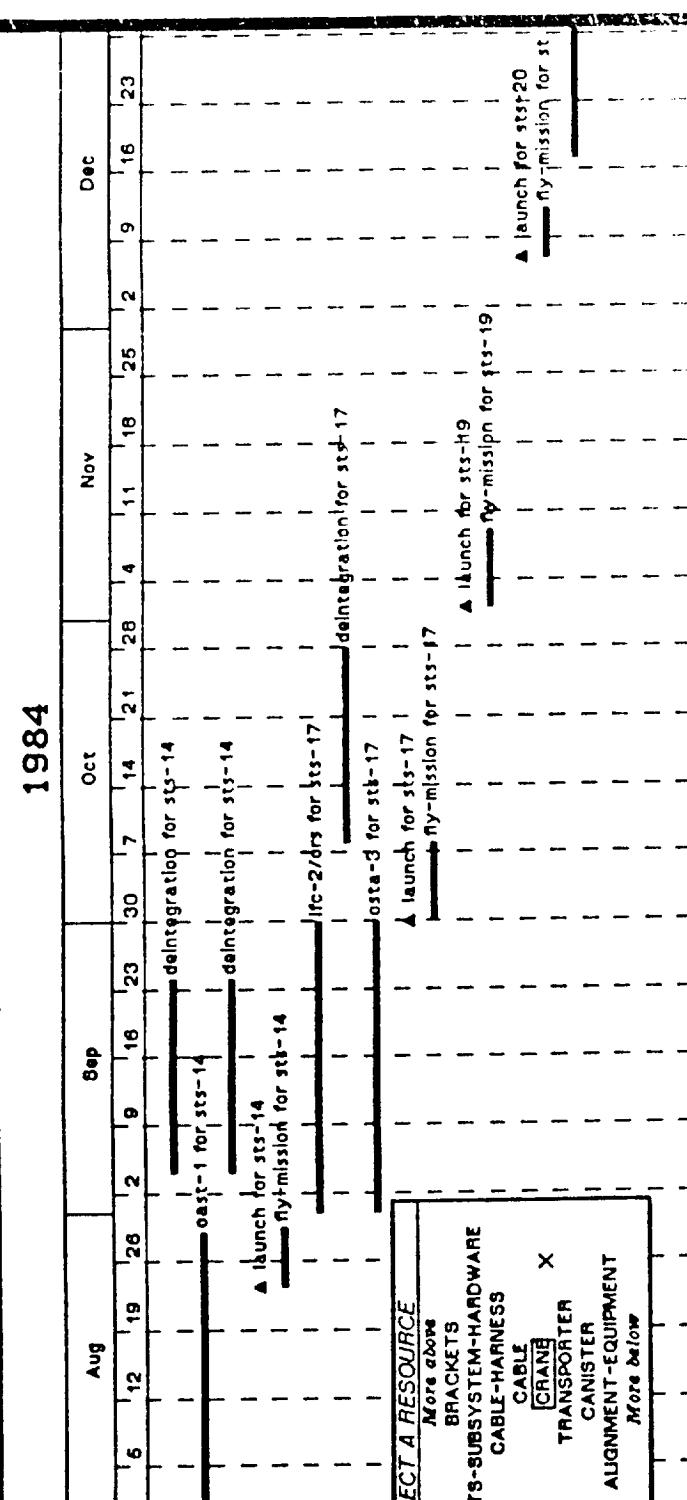
CRANE

X

TRANSPORTER

CANISTER

AUGMENT-EQUIPMENT
More below



Resource Pane

CRANE

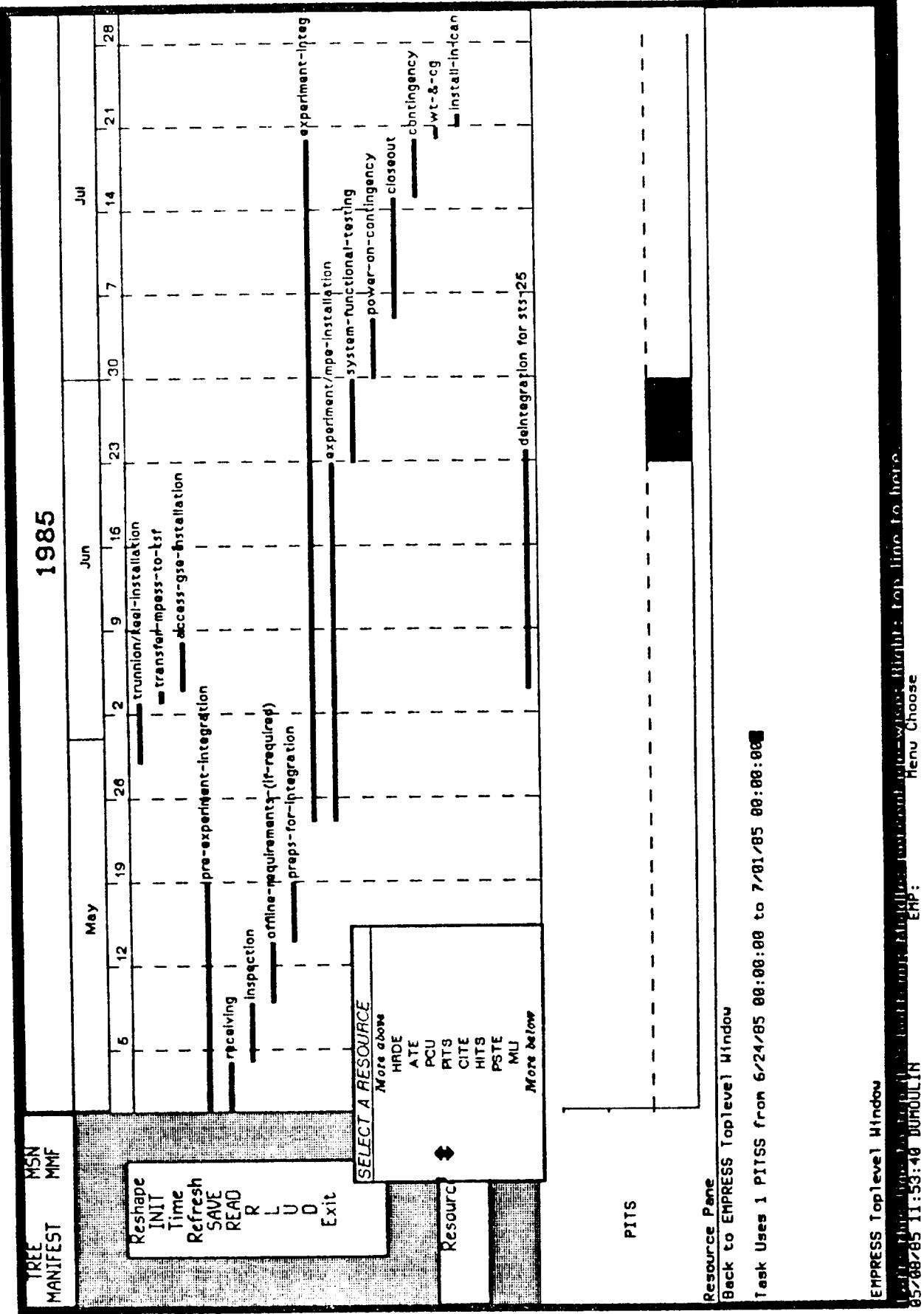
Task Uses 1 CRANES from 9/06/84 00:00:00 to 9/07/84 00:00:00
Task Uses 1 CRANES from 10/06/84 00:00:00 to 10/07/84 00:00:00
Task Uses 1 CRANES from 11/21/84 23:00:00 to 11/22/84 23:00:00
Task Uses 1 CRANES from 11/22/84 23:00:00 to 11/23/84 23:00:00

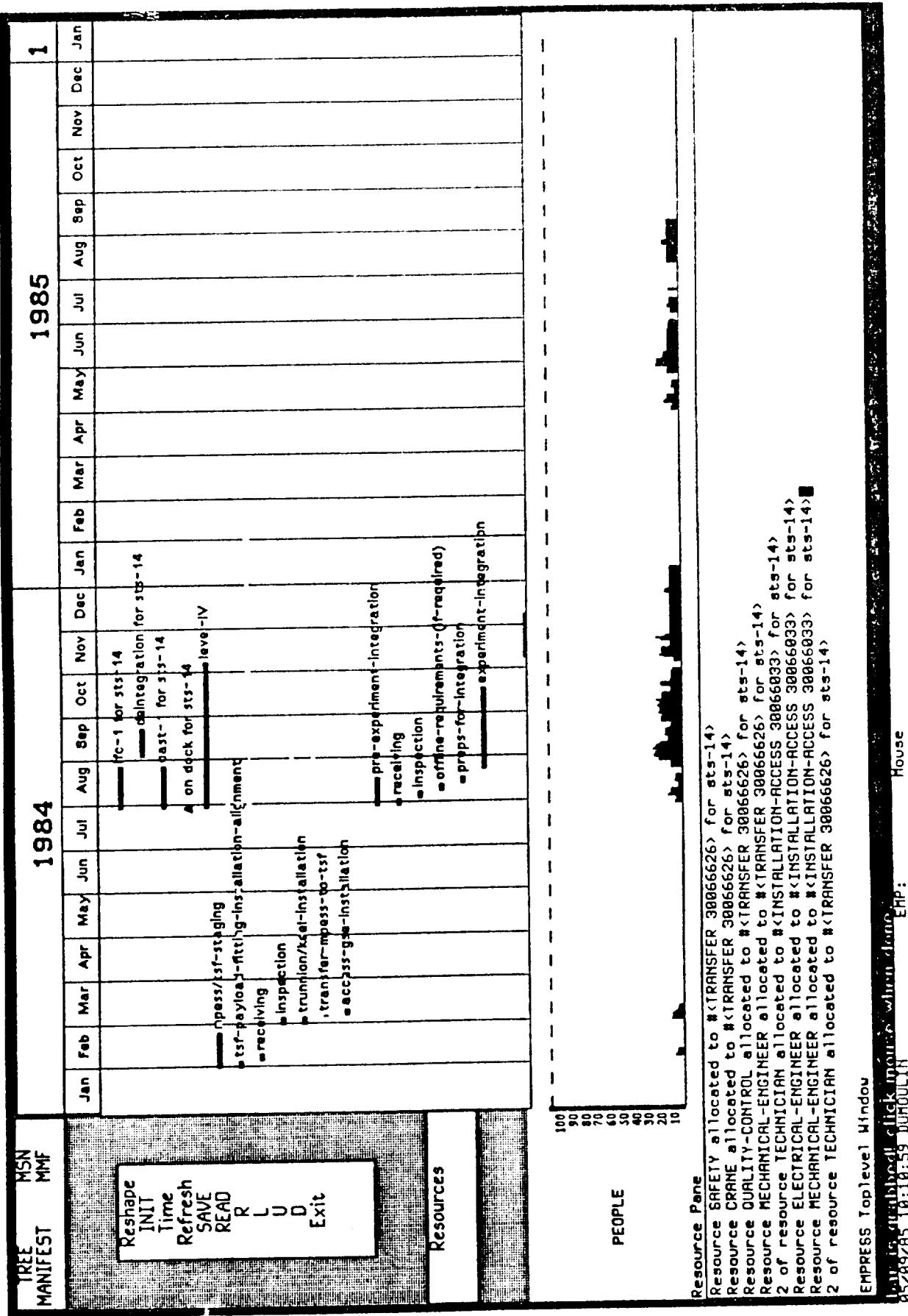
EMPRESS Top level Window

05/08/85 11:23:34 DURQUILYN

Menu Choose

File





WHERE'S THE ARTIFICIAL INTELLIGENCE?

A common question asked about many AI systems, is what makes this artificial Intelligence. AI has gotten so much attention in the past few years that people expect it to be a revolutionary new way to approach problems. In reality, AI is just a collection of tools and techniques that have been evolving for that last 20 years. Many of these techniques can be done using conventional programming languages and likewise many conventional techniques can be done using AI programming languages.

One of the most powerful tools an AI programmer has at his or her disposal is a rule based inference engine. If a problem is difficult to solve by conventional techniques, it may be easy to solve by inferencing. HOWEVER, if a particular problem is well known, well defined, and solvable, conventional techniques will almost always produce a solution in less computer time. The systems that make up the EMPRESS system use conventional techniques when they can, but each can escape to an inference engine when necessary. They also make heavy use of object orientated programming techniques.

Actual programming for EMPRESS has been under way for the last 5 months and the prototype is projected to be completed in September of 1985. Work on the inference engine is progressing but currently only the Resource Manager is rule driven. Over the next few months, rules files will be added to the Schedule Manager and the Constraints Manager to help them resolve situations that the currently cannot handle.

EXAMPLE OF SOME SIMPLE EMPRESS RULES

Assume that the failure information is in \$UMS as an object (the match should be (&allocation-failure :resource &resource))

1. If a resource is unavailable (at a time t for a duration d) and the resource is not an aggregate class type then try to find an alternate that is available under the same conditions

```
((&allocation-failure :resource &resource)
(&resource :type &type-)
($req &type->'aggregate))
((assert &goal :achieve 'find-alternate)
(assert &goal :object &resource)
(assert &goal :args &allocation-failure))
```

2. If a resource is unavailable (at a time t for a duration d) then try to move the need to another time

```
((&allocation-failure :resource &resource))
((assert &goal :achieve 'move-need)
(assert &goal :object &resource)
(assert &goal :args &allocation-failure))
```

3. If a resource is unavailable (at a time t for a duration d) then try to identify another candidate for moving and try to move that task

```
((&allocation-failure :resource &resource))
((assert &goal :achieve 'find-alternate)
(assert &goal :args &resource &allocation-failure))
```

FUTURE AI PROJECTS IN CARGO OPERATIONS

WORK IS IN PROGRESS ON A SMART-TERMINAL INTERFACE TO OBSOLETE TEST EQUIPMENT THAT IS TOO EXPENSIVE TO REPLACE. THIS IS AN IBM PC/AT INTERFACED TO THE SPACELAB LEVEL IV FLIGHT SIMULATION COMPUTER (MITRA 125S). IT ACTS LIKE A TELETYPE (ASR 33) EXCEPT IT CAN RESPOND TO CERTAIN ERROR MESSAGES.

SMART SOFTWARE PROGRAMS THAT LOOK AT SPACELAB SYSTEMS SELF-TEST DATA AND ALERT THE OPERATOR WHEN ERRORS OCCUR. CURRENTLY THIS SOFTWARE IS WRITTEN IN PERKIN-ELMER ASSEMBLY LANGUAGE ON THE PAYLOAD CHECKOUT UNIT (PCU), BUT WILL BE RE-IMPLEMENTED ON A SYMBOLICS 3670 RUNNING ART.

DESIGNS OF CHECK-OUT SYSTEMS FOR CARGO OPERATIONS TO UPGRADE CURRENT CAPABILITY AND TO REPLACE OBSOLETE EQUIPMENT ARE BEING DESIGNED WITH HOOKS FOR ARTIFICIAL INTELLIGENCE. (THE NEW PARTIAL PAYLOAD CHECKOUT SYSTEM (PPCU) UPGRADE TO THE PCU FOR CHECKOUT OF FLEX-MDM PAYLOADS WILL HAVE ETHERNET INTERFACES.

LOX EXPERT SYSTEM

CARL DELAUNE

This presentation described an expert system that diagnoses faults in the Shuttle LOX system at KSC. The problem being addressed is the situation in which a sensor failure in the LOX system may appear, to the current monitoring system, to be a LOX hardware failure. The resulting action in this situation is that the LOX loading process is reversed. Since this is a time-consuming process, a sensor failure that occurs close to launch or is not quickly diagnosed may cause a launch postponement. The LES contains schematics of the LOX system in frame form. It uses the constraints provided by this information plus current measurement values from the sensors in the LOX system to distinguish between sensor failures and cryogenic hardware failures and then uses a rule-based diagnostic scheme to find candidate causes of the observed problem. It appears to work quite quickly, requiring about one minute, and to work about as well as a human trouble-shooter.

WHEN A SENSOR FAILS

- INSTRUMENTATION COMPRISSES A COMPLEX ELECTROMECHANICAL NETWORK
- LAUNCH OPERATIONS HAVE BEEN PLAGUED BY INSTRUMENTATION FAILURES
- WHEN A SENSOR FAILS, LOX SYSTEM SAFED BY LPS
- EXPERTS TRACE THROUGH SCHEMATICS TO DETERMINE WHETHER THE PROBLEM IS "REAL" (ie CRYO HARDWARE) OR INSTRUMENTATION ERROR
- THIS TROUBLESHOOTING PROCESS IS MANUAL, ERROR PRONE, SLOW
- IF NOT RESOLVED QUICKLY, THE PROBLEM IS ASSUMED TO BE REAL AND THE LOADING OPERATION IS REVERTED
- INSTRUMENTATION SYSTEM HIGHLY REDUNDANT - USUALLY HAVE ENOUGH INFORMATION TO RESOLVE THE PROBLEM
- WOULD LIKE TO IMPROVE RELIABILITY AND SPEED OF TROUBLESHOOTING PROCEDURES

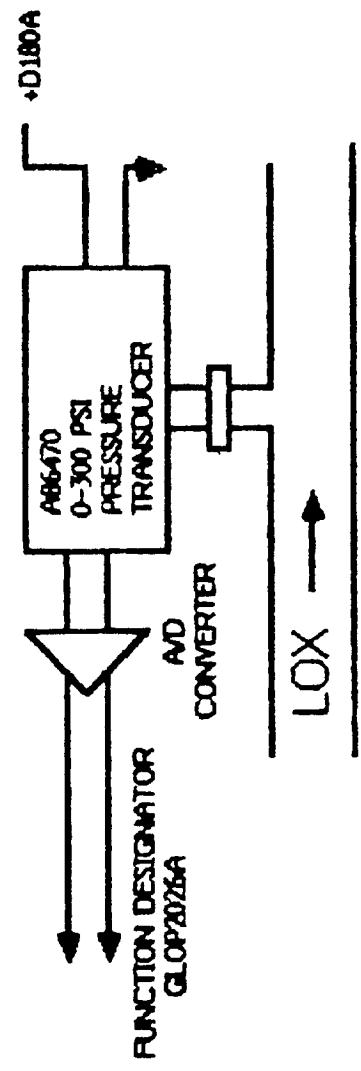
AN ENGINEER'S ASSISTANT

- CONTAINS ELECTRICAL SCHEMATIC DIAGRAMS ON A DATABASE
(INFORMATION CAN BE FOUND QUICKLY, IN LOGICAL ORDER)
- PERFORMS PRELIMINARY PROBLEM DIAGNOSIS BY CHECKING ANALOG MEASUREMENTS FOR INTERNAL CONSISTENCY
- INITIATES AND CONDUCTS TROUBLESHOOTING PROCEDURES
- NOTE: IF A "REAL" PROBLEM HAS OCCURRED IN THE CRYO SYSTEM THERE WILL BE NO INCONSISTENCY IN INSTRUMENTATION LPS WILL CORRECTLY SAFE THE SYSTEM
- TRIES TO DUPLICATE THE REASONING OF HUMAN TROUBLESHOOTERS
 - (DOES THE SENSOR HAVE POWER? CHECK OTHERS ON THE SAME BUS)
 - (HAS THE SENSOR FAILED? CHECK REDUNDANT MEASUREMENTS)
- DOES NOT ISSUE COMMANDS TO LPS

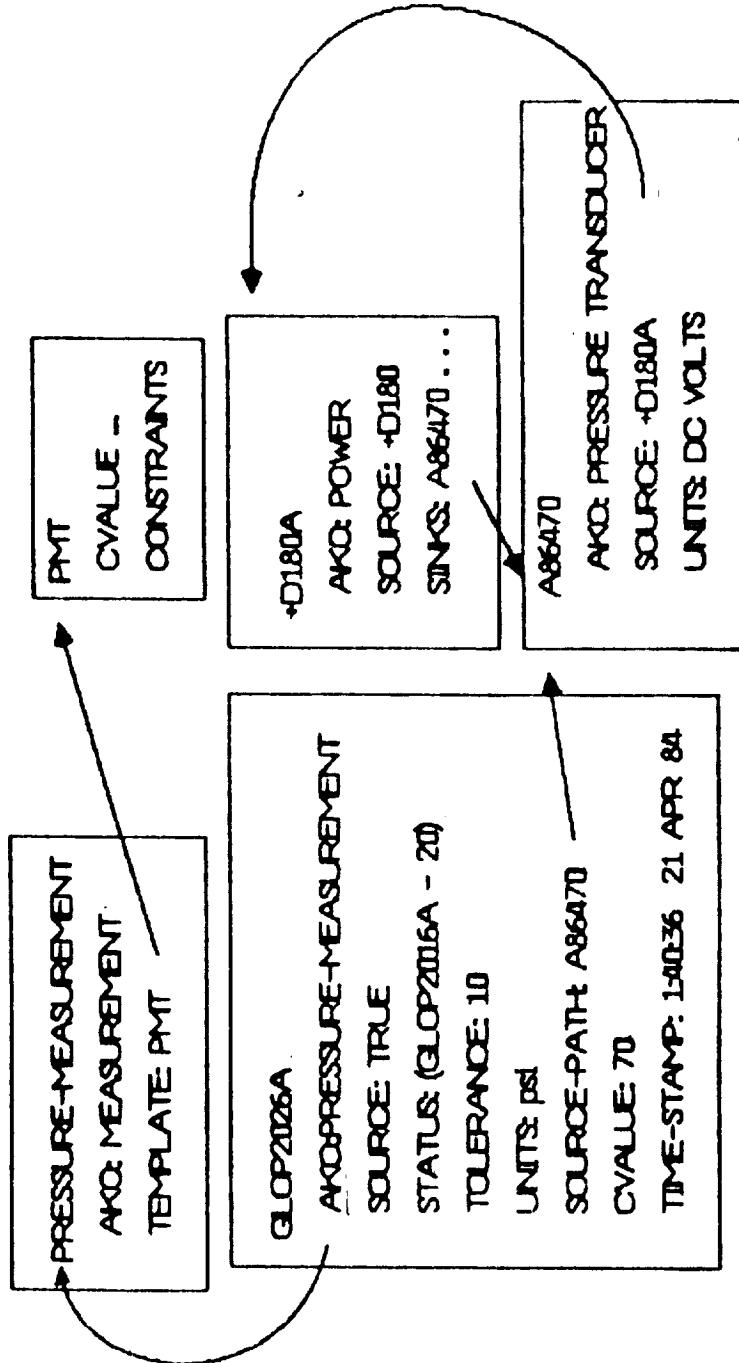
THE DATABASE

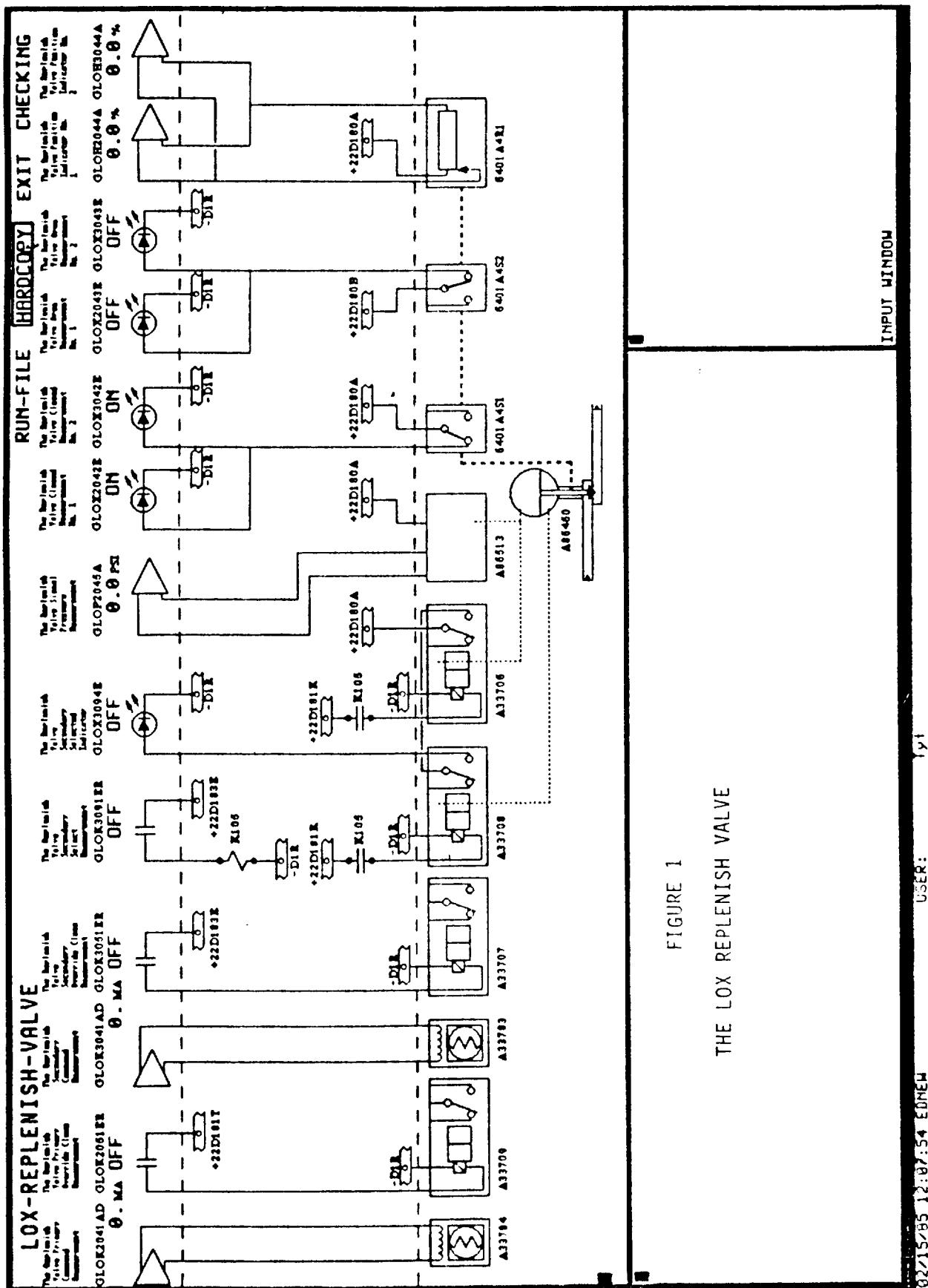
- ELECTRICAL SCHEMATICS SHOW COMPONENTS AND THEIR CONNECTIVITY
- LOX SYSTEM CONTAINS THOUSANDS OF COMPONENTS, COVERING HUNDREDS OF PAGES OF SCHEMATIC DIAGRAMS
- LES USES FRAMES FOR KNOWLEDGE REPRESENTATION
EACH MAJOR COMPONENT IS REPRESENTED AS A FRAME CONTAINING SLOTS WHICH DESCRIBE ITS PROPERTIES, VALUES, AND CONNECTIONS WITH OTHER COMPONENTS
- AUTOMATIC SCHEMATIC GENERATION AND SYSTEM DESIGN RETRIEVAL (ED NEWS SYSTEM)

ORBITER INLET PRESSURE

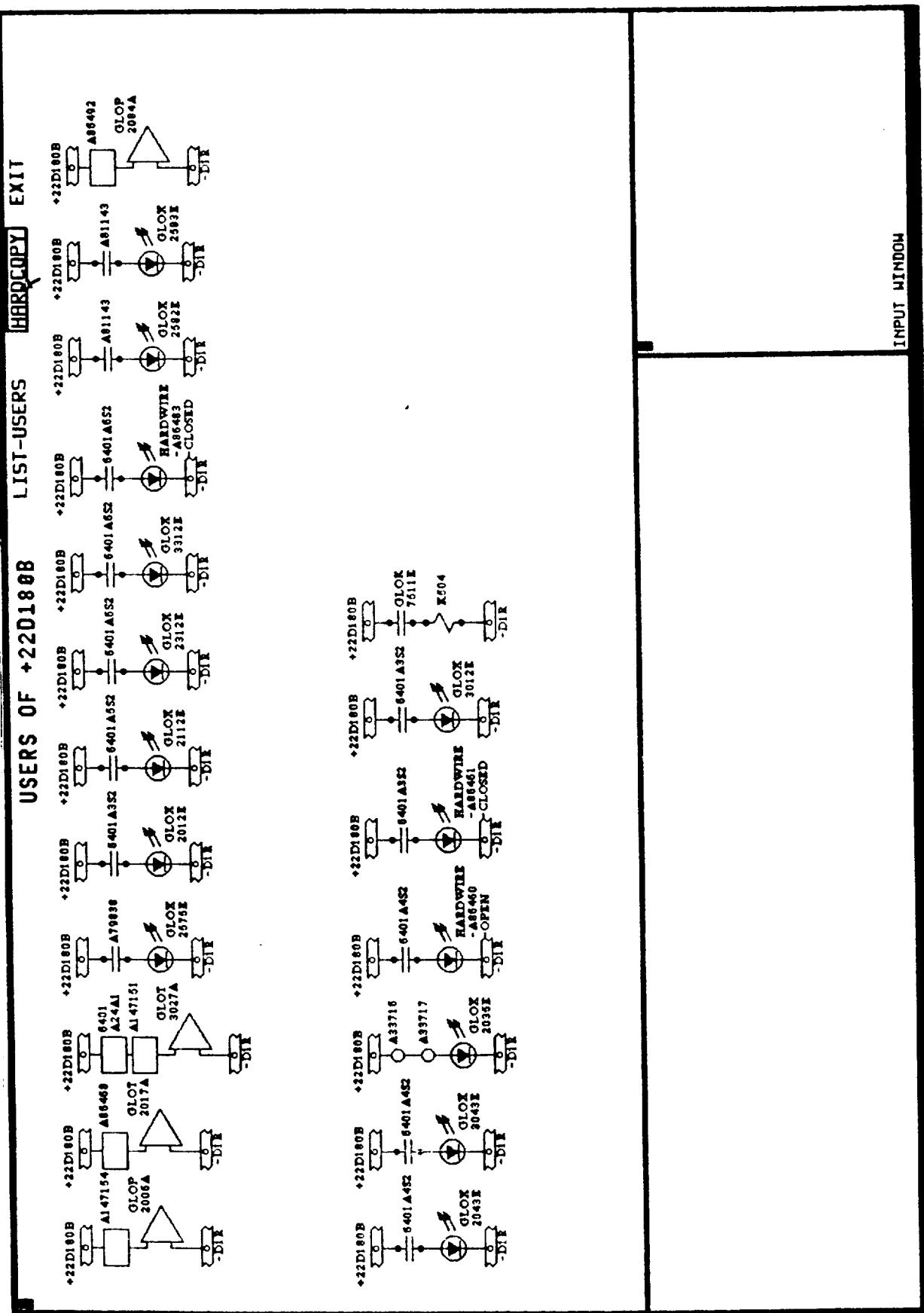


ORBITER INLET PRESSURE FRAMES





THE LOX REPLENISH VALVE



12712784 08:38:03 EDNEN

USER:

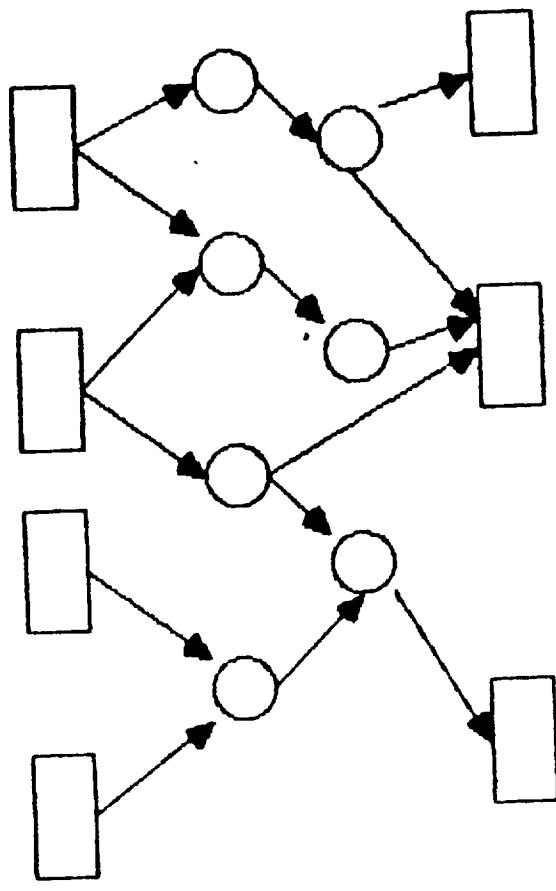
PROBLEM DETECTION

- LES MONITORS MEASUREMENTS IN THE LOX SYSTEM CHECKING FOR INCONSISTENT VALUES
- INCONSISTENCIES ARE DETECTED BY CHAINING THROUGH CONSTRAINTS IN THE FRAMES DATA BASE
- IF MEASUREMENTS ARE CONSISTENT AND THERE IS A PROBLEM IN THE CONTROL HARDWARE, LPS WILL SAFE THE SYSTEM
- LES DOES NOT MONITOR FOR FIXED OUT OF TOLERANCE CONDITIONS AS DOES UPS
- IF AN INCONSISTENT SET OF MEASUREMENTS IS DETECTED THEN THE DIAGNOSEER IS TRIGGERED

DIAGNOSE

- FUNCTIONAL DEPENDENCIES LINK COMMANDS TO MEASUREMENTS
- IF A MEASUREMENT IS ABNORMAL, ONE OF ITS CONTROLLING COMPONENTS MUST BE THE CULPRIT. ALL OF THEM ARE PLACED ON THE SUSPECT LIST.
- IF MULTIPLE MEASUREMENTS ARE ABNORMAL, THE INTERSECTION OF THEIR CONTROLLING COMPONENTS IS PLACED ON THE SUSPECT LIST
- IF TWO MEASUREMENTS DEPEND UPON THE SAME CONTROLLING COMPONENT AND ONE OF THEM IS NORMAL, IS THE CONTROLLING COMPONENT INNOCENT?
- WHAT VALUE WOULD THE CONTROLLING COMPONENT NEED TO PRODUCE THE ABNORMAL MEASUREMENT VALUE?
- THESE TECHNIQUES ARE USED TO PRUNE THE SUSPECT LIST. IF THE RESULT IS A SINGLE COMPONENT, THE CULPRIT IS FOUND
- OTHERWISE A LIST OF POSSIBLE CULPRITS IS RETURNED

DIAGNOUSER



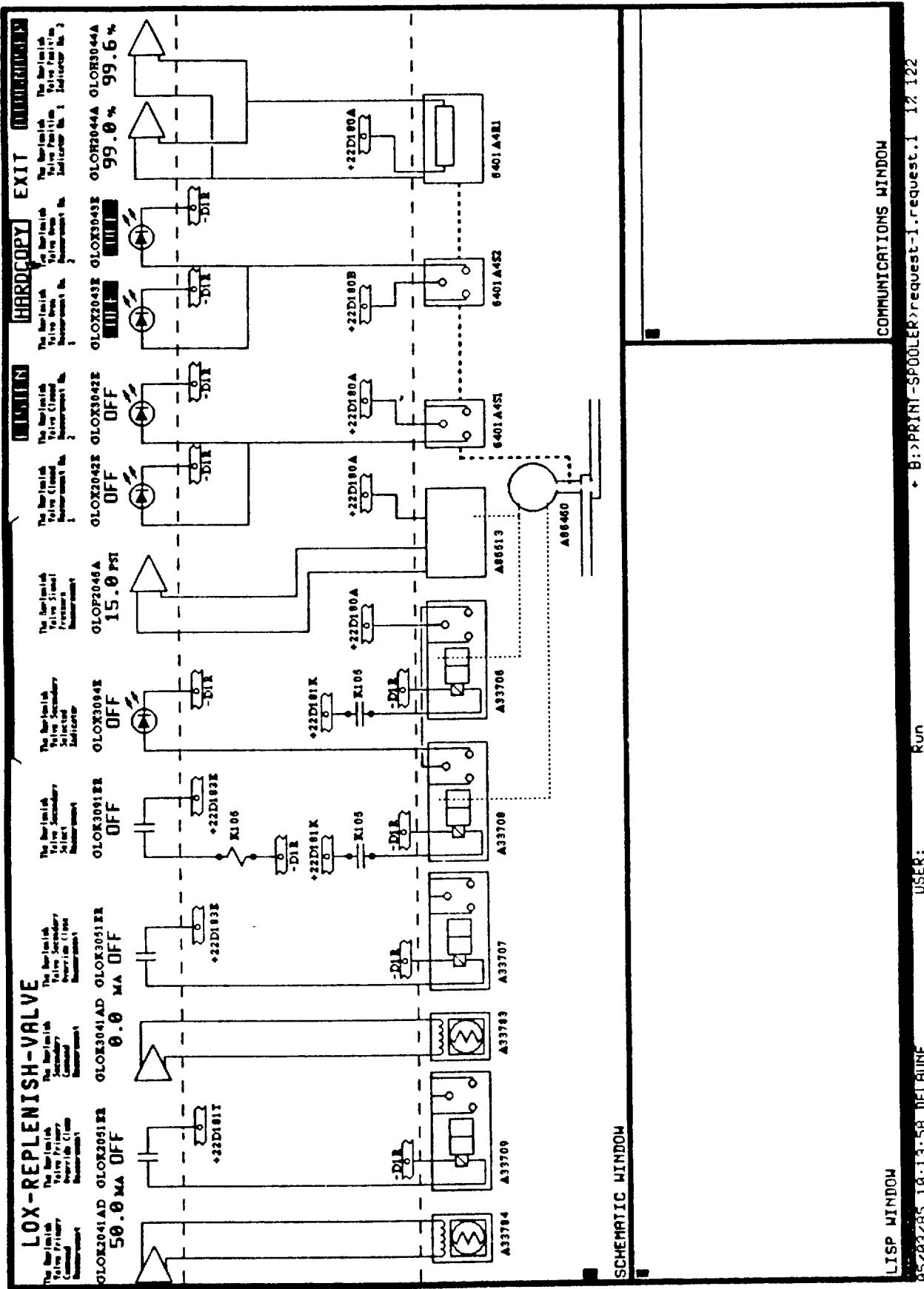
COMMANDS

COMPONENTS

MEASUREMENTS

RESULTS

- WORKS AT LEAST AS WELL AS HUMAN TROUBLESHOOTERS
- TAKES ABOUT A MINUTE
- GENERALITY
 - COULD WORK FOR LH2, OTHERS
 - NOT LIMITED TO TROUBLESHOOTING APPLICATIONS
- SAMPLE RESULTS - JAMESON



LISP WINDOW

05/03/85 10:13:58 DELRAINE

USTEK:

15

→ B:\PRINT-SPooler\request-1.request.1 12.122

***** I N T E R I M P R O B L E M R E P O R T *****
Friday the third of May, 1985; 10:12:11 am
REPORTED BY: LES the Lox Expert System

PROBLEM DESCRIPTION:

GLOX2043E the replenish valve open measurement no. 1 is not reading correctly.
It now reads: OFF ,but should read: ON .

ANALYSIS & TROUBLESHOOTING STEPS:

- 1.) GLOP2045A the replenish valve signal pressure measurement detects the current state of +22D180P, because if +22D180P was failed to OFF, then GLOP2045A would have to be reading between -0.5 and 0.5.
- 2.) GLOP2045A the replenish valve signal pressure measurement detects the current state of A33708, because if A33708 was failed to ON, then GLOP2045A would have to be reading between -0.5 and 0.5.
- 3.) GLOP2045A the replenish valve signal pressure measurement detects the current state of A33708, because if A33708 was failed to ON, then GLOP2045A would have to be reading between -0.5 and 0.5.
- 4.) GLOP2045A the replenish valve signal pressure measurement detects the current state of A33708, because if A33708 was failed to ON, then GLOP2045A would have to be reading between -0.5 and 0.5.
however, GLOP2045A is reading 15.0, thus clearing:
20-PSI-PRI, A33784, A33708, A33708, K105, and A33708.
Suspects now are: A86460, 6401A4S2, 6602A1-F2, +22D180B, and GLOX2043E.
- 5.) GLOX3043E the replenish valve open measurement no. 2 is NOT reading correctly thus clearing:
GLOX2043E.
Suspects now are: A86460, 6401A4S2, 6602A1-F2, and +22D180B.
- 6.) GLOH3044A the replenish valve position indicator no. 2 detects the current state of +22D180P, because if +22D180P was failed to OFF, then GLOH3044A would have to be reading between -5.0 and 5.0.
- 7.) GLOH3044A the replenish valve position indicator no. 2 detects the current state of A86460, because if A86460 was between 0.0 and 93., then GLOH3044A would have to be reading between -5.0 and 98..
however, GLOH3044A is reading 99.0, thus clearing:
A86460.
Suspects now are: 6401A4S2, 6602A1-F2, and +22D180B.
- 8.) GLOX2035E replenish valve secondary pressures okay measurement detects the current state of +22D180B, because if +22D180B was failed to OFF, then GLOX2035E would have to be reading OFF.
however, GLOX2035E is reading ON, thus clearing:
6602A1-F2 and +22D180B.
Suspects now are: 6401A4S2.

Friday the third of May, 1985; 10:12:28 am
At this point it appears that the most likely single point failure is
6401A4S2 the replenish valve open limit switch
The rest of the measurements will be searched for conflicting evidence.

9.) The balance of the RELATED MEASUREMENTS have been examined,
and cannot add additional information to the above analysis.

CONCLUSION:
It is determined that the most likely single point failure is
6401A4S2 the replenish valve open limit switch

Thank you----LES
Friday the third of May, 1985; 10:12:30 am

***** R E F E R E N C E I N F O R M A T I O N *****

LIST OF SUSPECTS EXAMINED:

SUSPECT	PRESSURE
20-PSI-PRI the 20 psi primary pressure source	PSI
A33784 the replenish valve primary transducer	CURRENT-TO-AIR-TRANSDUCER
A33709 the replenish valve signal primary override solenoid	SOLENOID
A33708 the replenish valve signal pressure secondary select	SOLENOID
K105 the replenish valve secondary select relay	RELAY
A33708 the replenish valve supply pressure secondary select	SOLENOID
A86460 the replenish valve	ANALOG-VALVE
6401A4S2 the replenish valve open limit switch	LIMIT-SWITCH
6602A1-F2 the fuse F2 in MLP panel 6602A1	FUSE
+22D180B the MLP DC power bus number +22D180B	POWER-BUS
GLOX2043E the replenish valve open measurement no. 1	OFF
	DISCRETE-VALVE-MEASUREMENT

LIST OF MEASUREMENTS USED FOR THE EVALUATION:

GLOP2045A the replenish valve signal pressure measurement	15.0 PSI	ANALOG-PRESSURE-MEASUREMENT
GLOX3043E the replenish valve open measurement no. 2	OFF	DISCRETE-VALVE-MEASUREMENT
GLOX3042E the replenish valve closed measurement no. 2	OFF	DISCRETE-VALVE-MEASUREMENT
GLOH2042E the replenish valve closed measurement no. 1	OFF	DISCRETE-VALVE-MEASUREMENT
GLOH3044A the replenish valve position indicator no. 2	99.0 %	ANALOG-VALVE-MEASUREMENT
GLOH2044A the replenish valve position indicator no. 1	99.0 %	ANALOG-VALVE-MEASUREMENT
GLOX2035E replenish valve secondary pressures okay measurement	ON	DISCRETE-PRESSURE-MEASUREMENT

8LOX3094E the replenish valve secondary selected indicator
8LOX2375E the 750 psi gn2 sup press no 1

OFF
ON

DISCRETE-VALVE-MEASUREMENT
DISCRETE-VALVE-MEASUREMENT

FURTHER WORK

- CONNECT TO LAUNCH PROCESSING SYSTEM FOR REAL TIME ANALYSIS
- EXPAND KNOWLEDGE BASE
 - WORK BACK TO THE DIGITAL SYSTEM
 - ADD LH₂ AND OTHER FLUID SYSTEMS
- SAVE AND MANIPULATE HISTORICAL DATA
- PORT TO SMALLER COMPUTERS
- CONTROL !
- BETTER WAYS TO CREATE KNOWLEDGE BASES

KATE

- KNOWLEDGE BASED AUTOMATIC TEST EQUIPMENT
- KNOWLEDGE BASE AND DIAGNOSTIC CAPABILITIES FROM IES
- INTERFACE HOST COMPUTER TO EQUIPMENT UNDER TEST VIA SENSOR AND CONTROL SYSTEM
- WILL DESIGN TESTS FOR EQUIPMENT, THEN EXECUTE, CONTROL, MONITOR, AND ANALYZE THEM

This presentation describes a project to develop knowledge-based automatic test equipment using IBM PC-AT class micro-computers.

KATE IMPLEMENTATION

- SPEED IS NOT AN ISSUE - SYMBOLICS CLASS COMPUTER NOT NECESSARY
- COMMON LISP IS CLOSE ENOUGH TO ZETALISP TO PORT MOST LISP SOFTWARE
- A LARGE, FAST MICROCOMPUTER (LIKE AN IBM PC AT) WILL BE USED AS HOST FOR THE KATE SYSTEM
- WILL BE EQUIPPED WITH HARDWARE INTERFACE (IEEE 488 BUS)
- KATE WILL INPUT MEASUREMENTS (MONITOR) AND ISSUE COMMANDS THROUGH THIS BUS

\$\$\$\$

- \$25,000 MIT INITIAL STUDY - CDDF
- \$300,000 2 YEAR MITRE SUPPORT - CDDF & ETB
- \$220,000 SYMBOLICS - ETB
- \$85,000 KATE WORKSTATIONS AND HARDWARE
- SPACE STATION

ACKNOWLEDGEMENTS: BOB JIRKA, JPL
LEN FRIEDMAN, JPL

WEATHER FORECASTING

EXPERT SYSTEM

KSC is currently planning the development of an expert system to assist the USAF personnel who do the short-term weather forecasts for Shuttle launch and landing at KSC.

Presentation: KSC Robotics Development Laboratory
Speaker: V. Leon Davis

KSC is currently developing a Robotics Applications Laboratory that can serve as a test bed for the application of robotics to the hazardous conditions that are present during the servicing and launch of large rockets.

KENNEDY SPACE CENTER
TON DAVIS

KENNEDY SPACE CENTER
WEATHER FORECASTING EXPERT SYSTEM

● PROBLEM

- INCREASED STS PROCESSING, LAUNCH, AND LANDING FREQUENCY EXCEEDS MANUAL FORECASTING CAPABILITY
- CURRENT NOW-CASTING (0-6 HOURS) ACCURACY INADEQUATE TO SUPPORT LAUNCH AND LANDING
- UNIQUE KSC CLIMATOLOGY
- MAJOR MESO-SCALE DATA SYSTEM CREATES DATA LOG JAM
- USAF FORECASTER EXPERIENCE VS TURNOVER

KENNEDY SPACE CENTER

WEATHER FORECASTING EXPERT SYSTEM

● SOLUTION

- EVALUATE THE FEASIBILITY OF DEVELOPING A WEATHER FORECASTING EXPERT SYSTEM TO ASSIST THE WEATHER FORECASTERS
- DEVELOP A PROTOTYPE FORECASTING SYSTEM USING PART OF THE WEATHER DATA SYSTEM, WEATHER SCENARIOS, AND FORECASTING TECHNIQUES
- TEST THE SYSTEM USING ACTUAL DATA IN SUPPORT OF ACTUAL STS PROCESSING/LAUNCH/LANDING REQUIREMENTS
- EVALUATE PROTOTYPE TESTING PHASE AND DETERMING NEEDS AND FEASIBILITY OF DEVELOPING A FULLY OPERATIONAL WEATHER FORECASTING EXPERT SYSTEM
- DEVELOP COMPLETELY OPERATIONAL WEATHER FORECASTING EXPERT SYSTEM (PERHAPS IN CONJUNCTION WITH USAF)

TOM DAVIS
KSC

KENNEDY SPACE CENTER
WEATHER FORECASTING EXPERT SYSTEM

- PURPOSE OF WFEES
- CAPTURE FORECASTING DOMAIN EXPERTISE
- DEVELOP A SYSTEM "THAT CAN LEARN"
- PROVIDE A REAL-TIME AID TO FORECASTERS
- DEVELOP A SYSTEM THAT IS INTEGRATED INTO THE MESO-SCALE DATA NETWORK
- PROVIDE TRAINING FOR NEW FORECASTERS

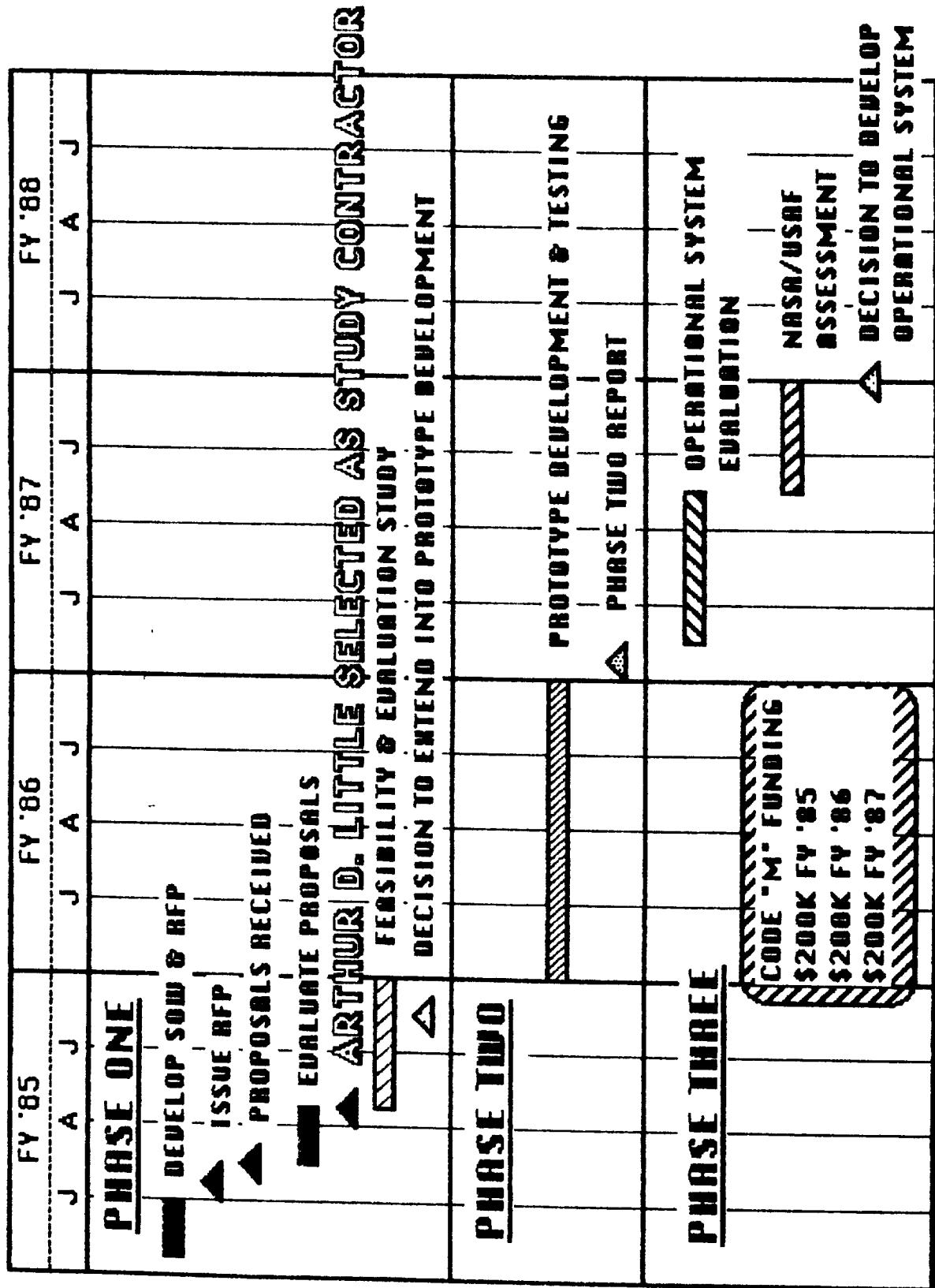
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WEATHER FORECASTING EXPERT SYSTEM

● FEASIBILITY STUDY

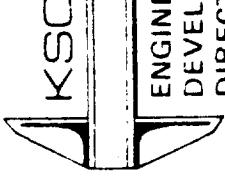
- EVALUATE STS FUNCTIONS REQUIRING WEATHER FORECASTING SUPPORT
- IDENTIFY KEY WEATHER SCENARIOS AND RELATION TO STS PROCESSING FUNCTIONS
- EVALUATE FORECASTING METHODS VS PROTOTYPE WFES SYSTEMS OPTIONS
- EVALUATE "PATTERN RECOGNITION" TECHNIQUES VS DATA SYSTEM AND USE IN WFES OPTIONS
- EVALUATE MESO-SCALE DATA SYSTEMS AND FORECASTING TOOLS VS USE IN WFES OPTIONS (CONSIDER FUTURE FULLY AUTOMATED SYSTEM)
- EVALUATE EXISTING KSC EXPERT SYSTEMS HARDWARE & SOFTWARE FOR USE IN WFES DEVELOPMENT
- PROVIDE COMPLETE PLAN FOR DEVELOPMENT OF PROTOTYPE WFES (SCHEDULES, RESOURCES, ETC.)

TOM DAVIS KSC

KENNEDY SPACE CENTER WEATHER FORECASTING EXPERT SYSTEM



TOM DAVIS
KSC



KSC
ENGINEERING
DEVELOPMENT
DIRECTORATE

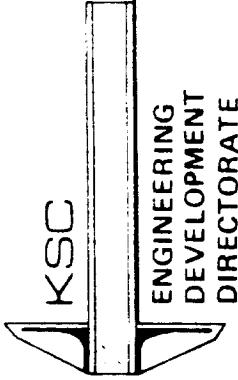
V. LEON DAVIS
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY
MAY. 16, 1985

KSC ROBOTICS DEVELOPMENT LABORATORY

BY: VIRGIL LEON DAVIS

ELECTRICAL LEAD FOR ROBOTIC CONTROL SYSTEMS
KSC ROBOTICS DEVELOPMENT TEAM

KSC is currently developing a Robotics Applications Laboratory that can serve as a test bed for the application of robotics to the hazardous conditions that are present during the servicing and launch of large rockets.



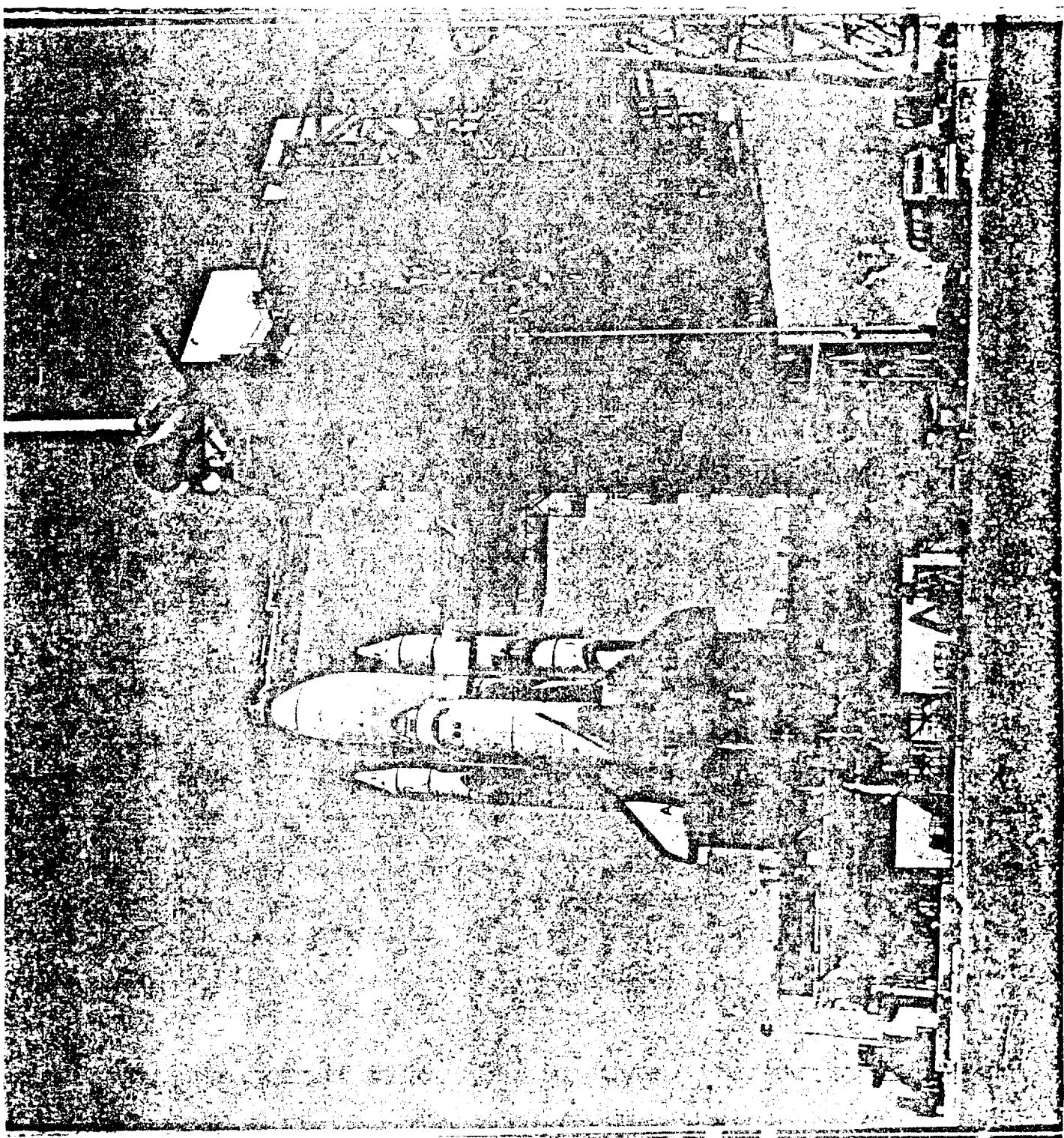
ENGINEERING
DEVELOPMENT
DIRECTORATE

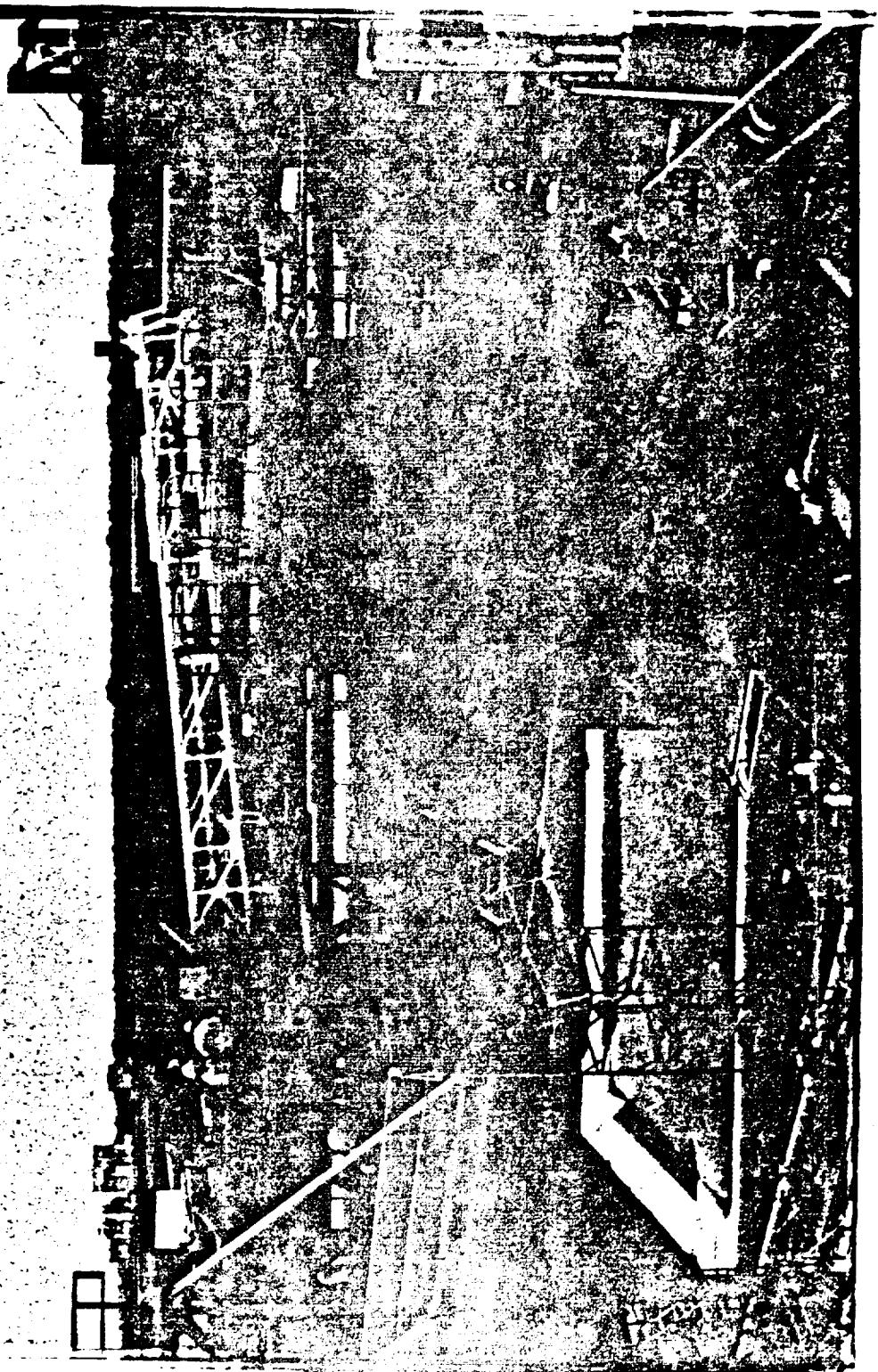
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

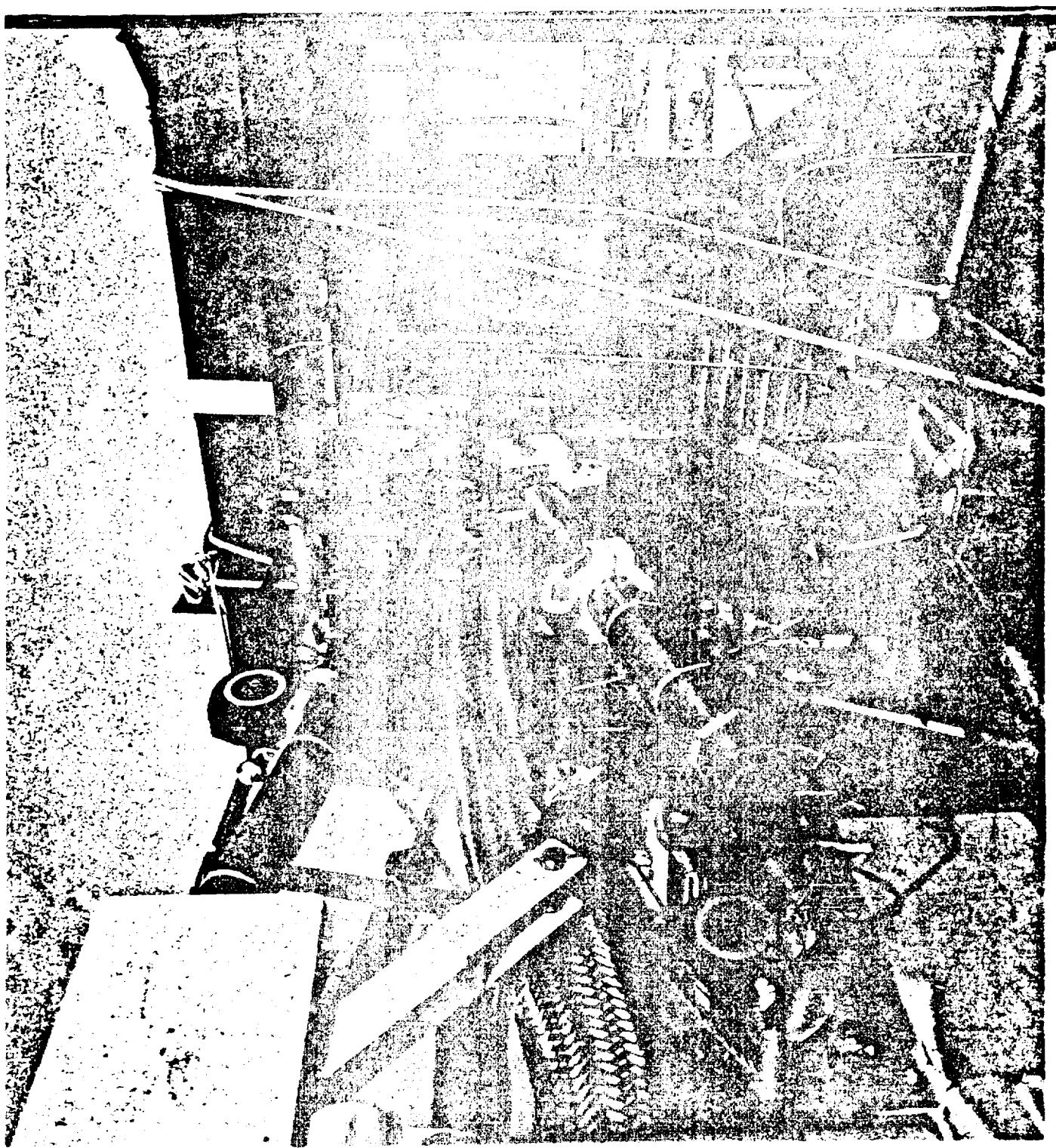
V. LEON DAVIS
MAY. 16, 1985

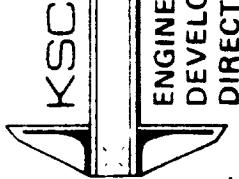
OUTLINE

- KSC PECULIAR PROBLEMS
- RESOLUTION METHODOLOGY
- DEVELOPMENT LABORATORIES ACTIVITIES
 - LAB A (FCTB)
 - LAB B (LETF) (Lunar Engineering Test Facility)
- APPLICATIONS
- INTERCENTER INTEGRATION









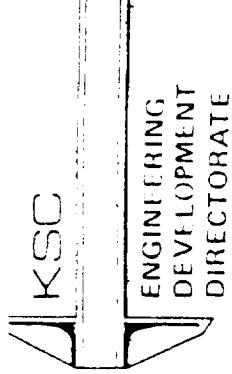
KSC ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

V. LEON DAVIS
MAY. 16, 1985

ENGINEERING
DEVELOPMENT
DIRECTORATE

DEVELOPMENT SYSTEM NEEDS FOR KSC PECULIAR PROBLEMS

- HEAVY LIFT (10 FT REACH) CAPABILITY
- ADAPTIVE SERVO PATH CONTROL
- REAL - TIME TARGET TRACKING
- TESTBED FOR SENSOR SUBSYSTEM DEVELOPMENT
- RECONFIGURABLE/EXPANDABLE CONTROL AND MONITOR SYSTEM
- UNIVERSAL DEVELOPMENT SYSTEM FOR VARIED APPLICATIONS



ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

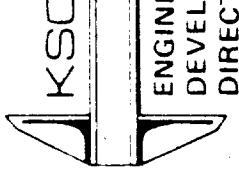
V. LEON DAVIS

ENGINEERING
DEVELOPMENT
DIRECTORATE

MAY. 16, 1985

OUTLINE

- KSC PECULIAR PROBLEMS
- RESOLUTION METHODOLOGY
- DEVELOPMENT LABORATORIES ACTIVITIES
 - LAB A (FCTB)
 - LAB B (LETF)
- APPLICATIONS
- INTERCENTER INTEGRATION



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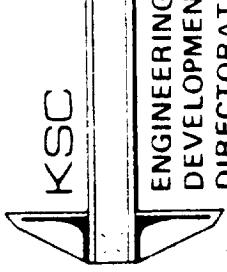
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

V. LEON DAVIS

MAY. 16, 1985

RESOLUTION METHODOLOGY

- PROJECT TITLE: ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY
- OBJECTIVES:
PROVIDE TRAINING AND PRACTICAL APPLICATIONS TO DEVELOP A ROBOTIC CAPABILITY IN DESIGN ENGINEERING,
- APPROACH:
APPLY CURRENT AND ADVANCED ROBOTIC TECHNOLOGY TO TIME CRITICAL, HAZARDOUS, AND REPETITIVE LABOR INTENSIVE OPERATIONS;
- APPROACH:
APPLY AUTOMATED GROUND OPERATIONAL TECHNIQUES (FOR LOADING/UNLOADING HYPERGOLIC/CRYOGENIC FUELS) TO FUTURE GROUND SERVICING SYSTEMS FOR ADVANCED LAUNCH VEHICLES AND PAYLOADS.
- APPROACH:
PROCURE/DESIGN/INSTALL A ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY (RADL) IN WHICH ROBOTIC'S HARDWARE, ACTUATORS, GRIPPERS, ALGORITHMS, SOFTWARE, SENSORS AND CONTROL SYSTEMS WILL UNDERGO CONCEPTUALIZATION, IMPLEMENTATION, EVALUATION, AND CHECKOUT USING A LARGE SCALE TEST ARTICLE.



ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

V. LEON DAVIS

MAY. 16, 1985

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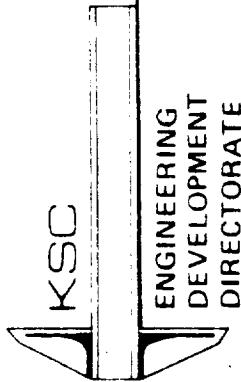
RESOLUTION METHODOLOGY (CONT'D)

- PRODUCTS:
 - ELECTROSTATIC TEST CHAMBER ROBOT
 - REMOTE UMBILICAL CONNECTION/DISCONNECTION
 - HYPERGOLICS, CRYOGENICS, ELECTRICAL, COMMUNICATIONS
 - HYDRAZINE SERVICING CART PIGGYBACK ROBOT ARM
 - LITHIUM HYDROXIDE CANISTER RESERVICING PROTOTYPE
 - ULTRASONIC PGHM DOCKING MECHANISM TESTING
 - OTHER HAZARDOUS, TIME CRITICAL, OR REPETITIVE OPERATIONS

● RESOURCES:	FUND SOURCE	FY-84	FY-85	FY-86	FY-87	FY-88
MATERIALS:	CDDF	\$100K	---	---	---	---
CODE M		---	\$150K	\$200K	\$200K	---
ETB	---	\$220K	\$400K	\$525K	\$550K	\$600K

C. S. MANPWR. (MY):

2 3 5 7 10



ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

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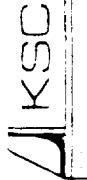
V. LEON DAVIS

MAY. 16, 1985

KSC ROBOTIC DEVELOPMENT LABORATORIES

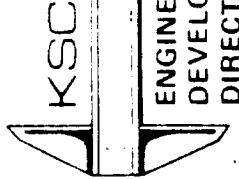
- LAB A (FCTB)
 - TRAINING DEVICES
 - SENSOR DEVELOPMENT
 - END-EFFECTOR DEVELOPMENT
 - SMALL PROJECTS

- LAB B (LETF)
 - COMPLEX WORK CELLS
 - SMART SYSTEMS INTEGRATION
 - VISION
 - TRACKING
 - GRAPHICS
 - LARGE ROBOTIC APPLICATIONS



OUTLINE

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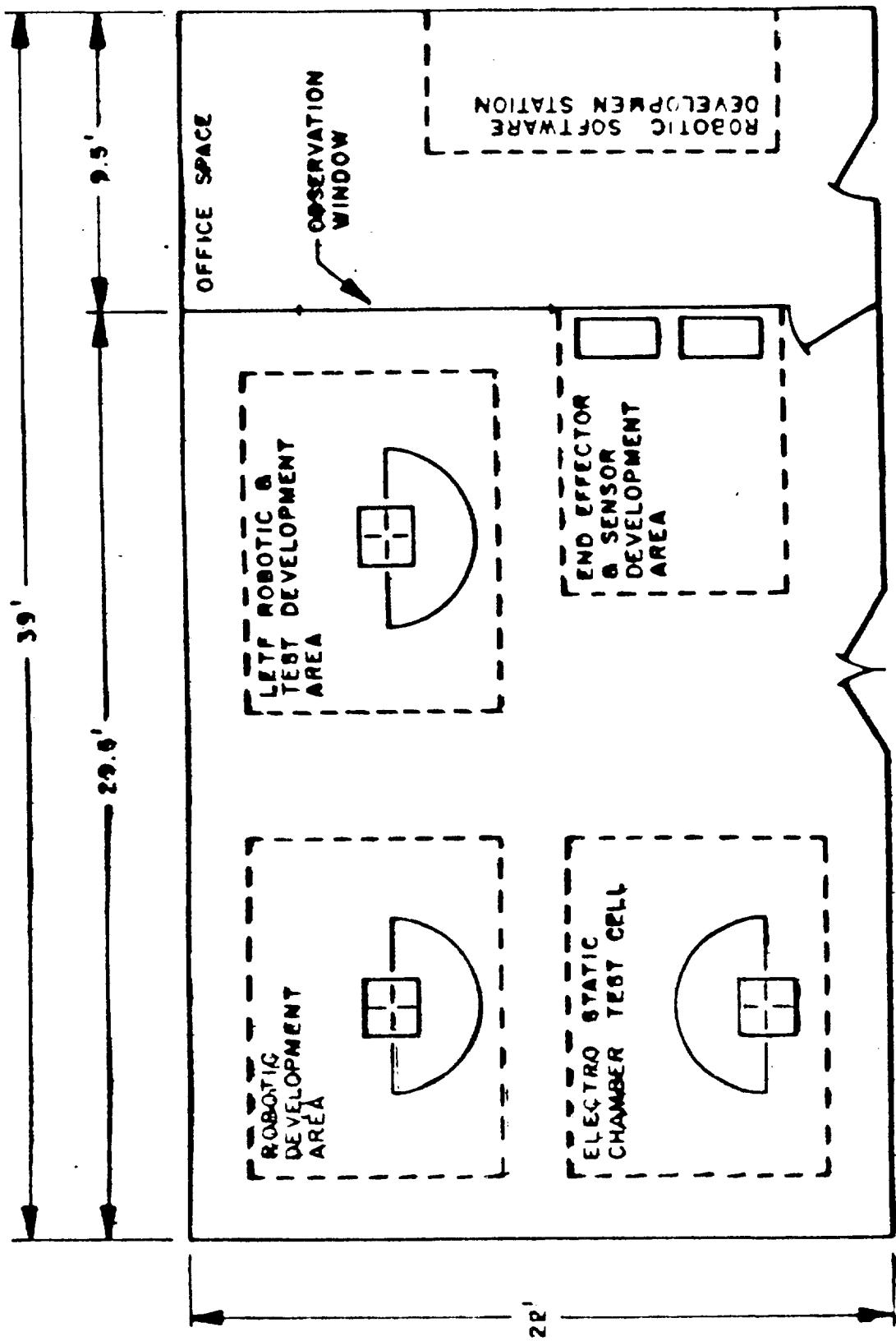
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

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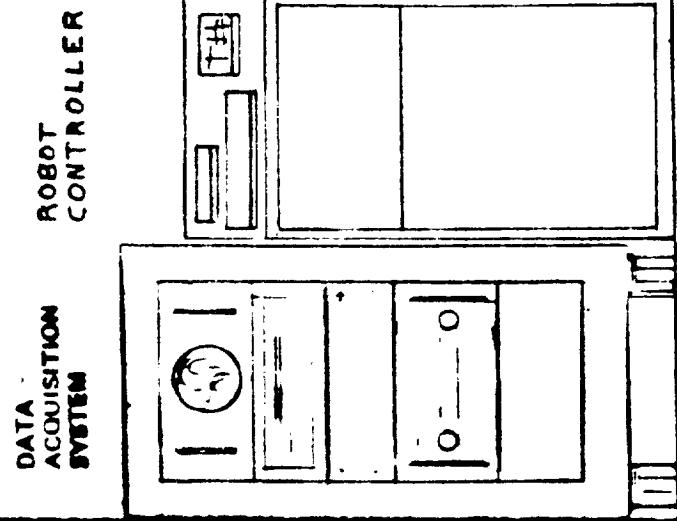
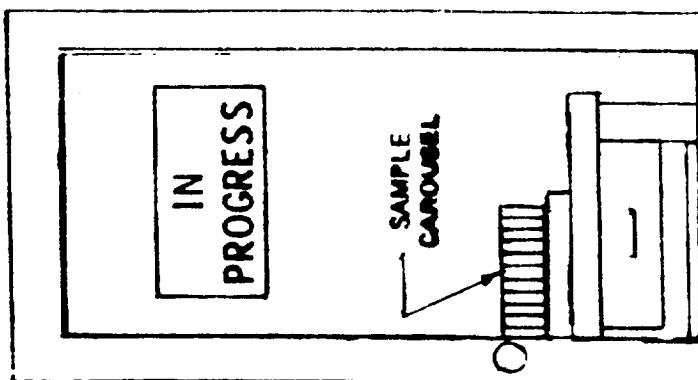
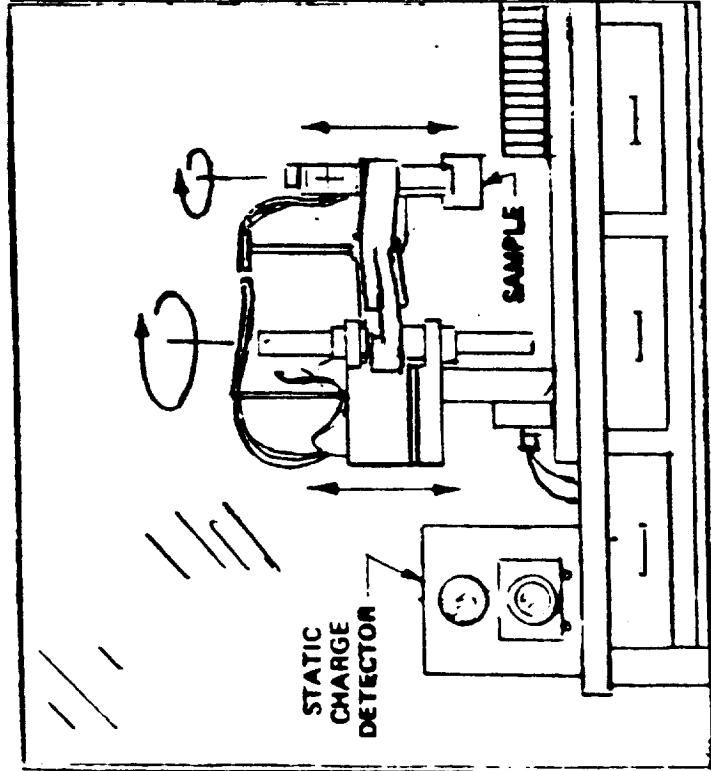
DEVELOPMENT LABORATORY ACTIVITIES

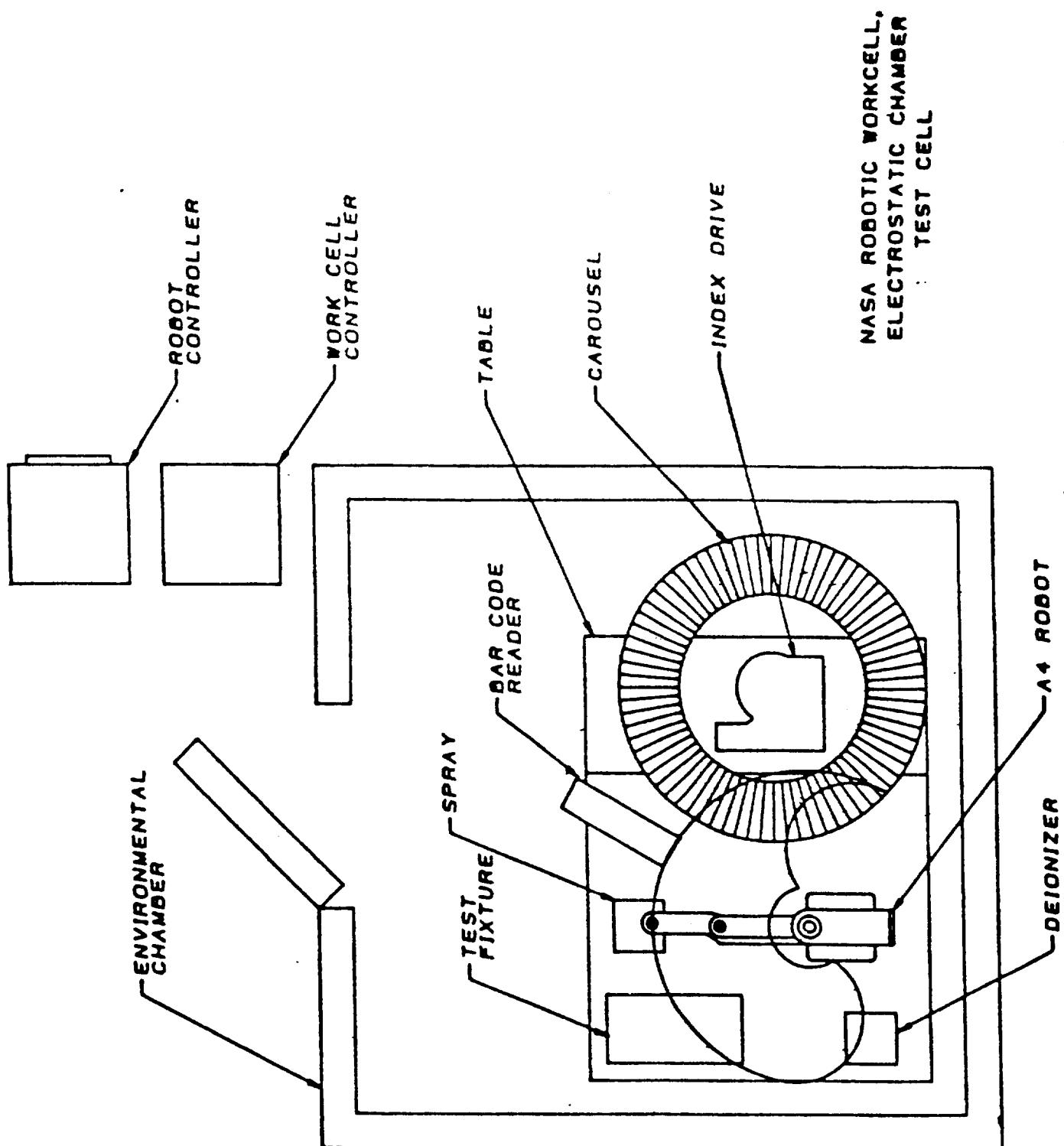
- LAB A (FCTB)
 - TRAINING DEVICES
 - TWO FIXED ROBOTICS ARMS, CONTROL SYSTEMS & TRAINING CURRICULUM
 - ONE MOBILE ROBOTICS TRAINING DEVICE
 - SENSOR DEVELOPMENT
 - ULTRASONIC, PROXIMITY, MAGNETIC FIELD ECHO
 - END-EFFECTOR DEVELOPMENT
 - SMALL PROJECTS
 - PNEUMATIC CARTESIAN ROBOT (ESS CARD TESTING)
 - ELECTROSTATIC TEST CHAMBER ROBOT

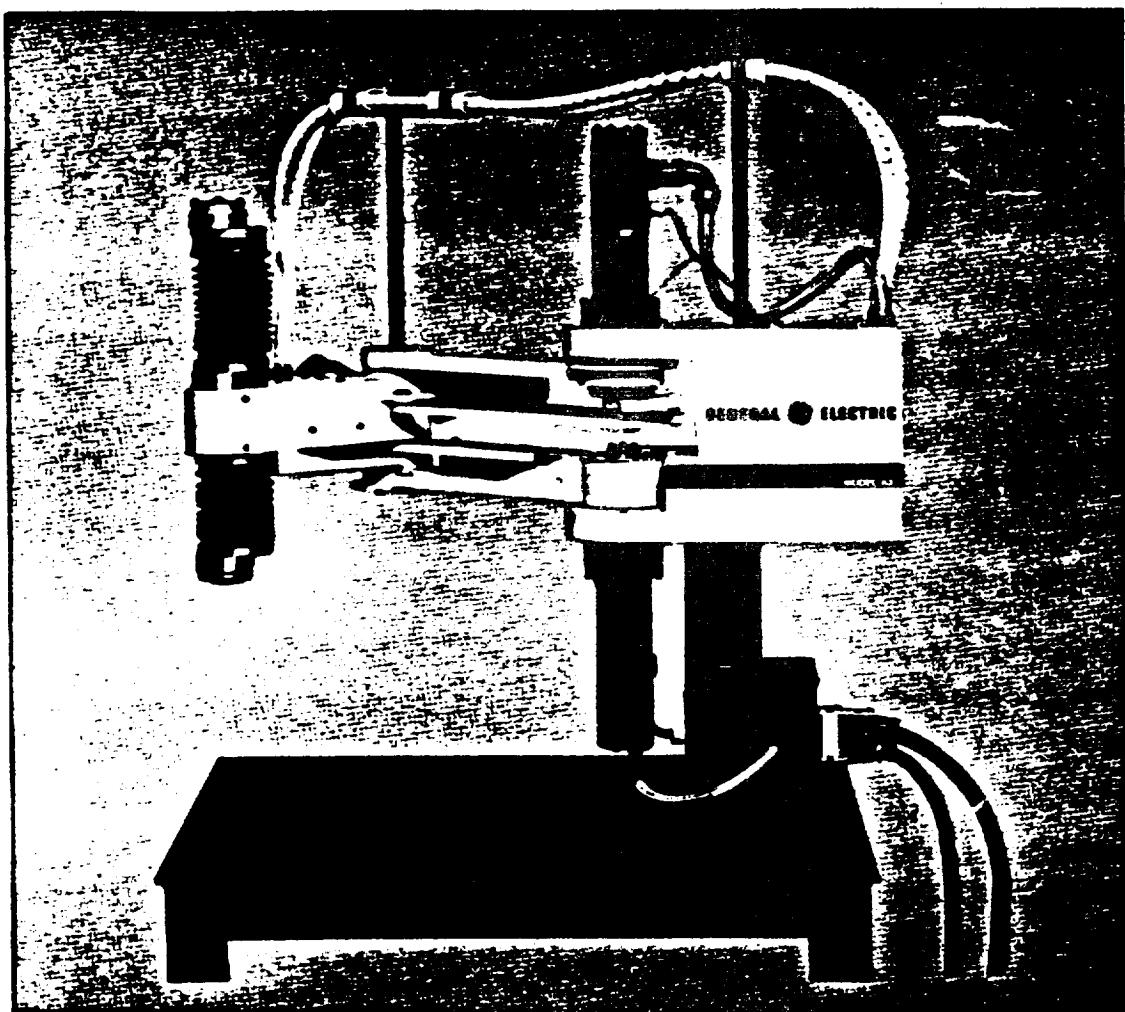
FCTB ROBOTIC LAB
ROOM 117 BLDG. M7-409

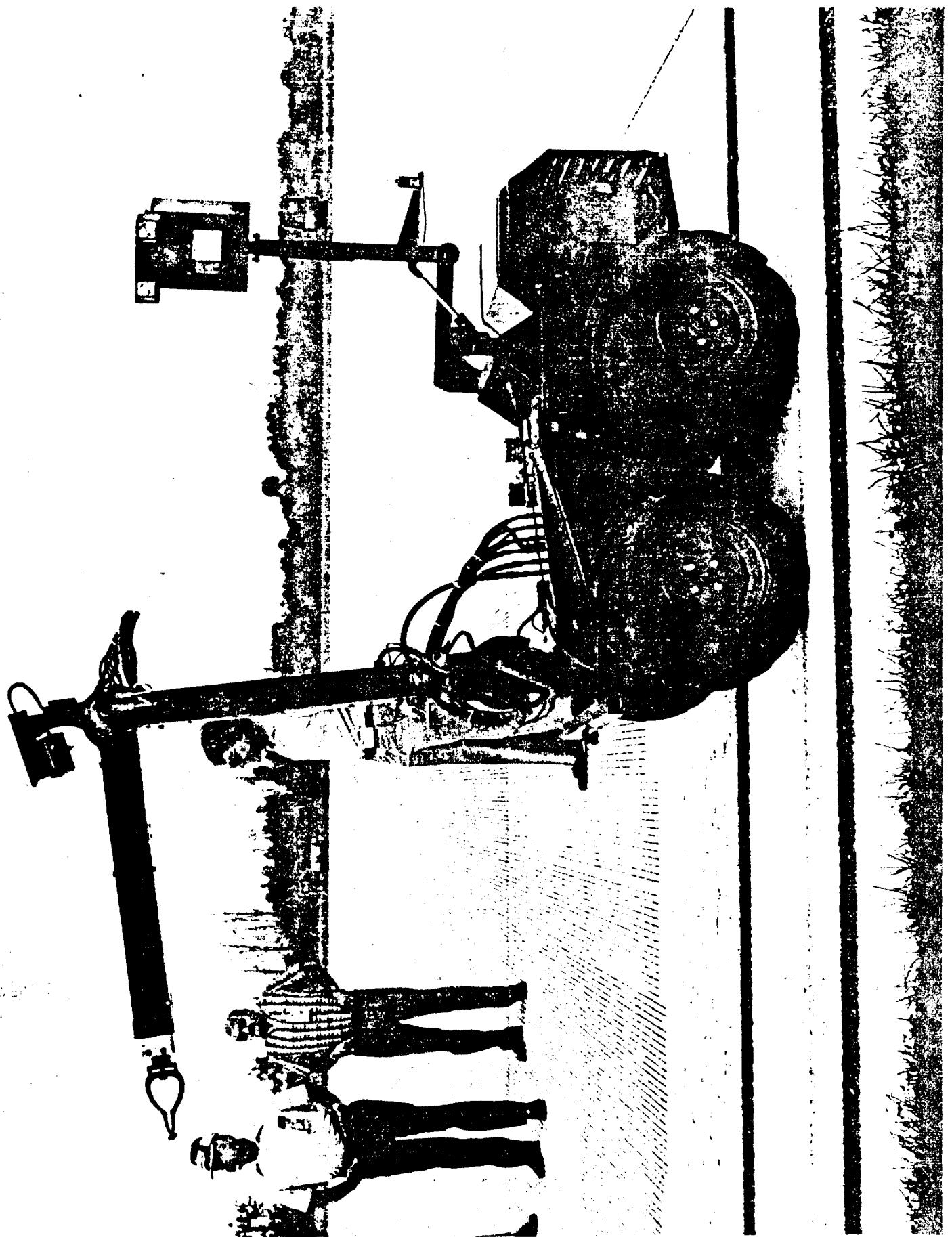


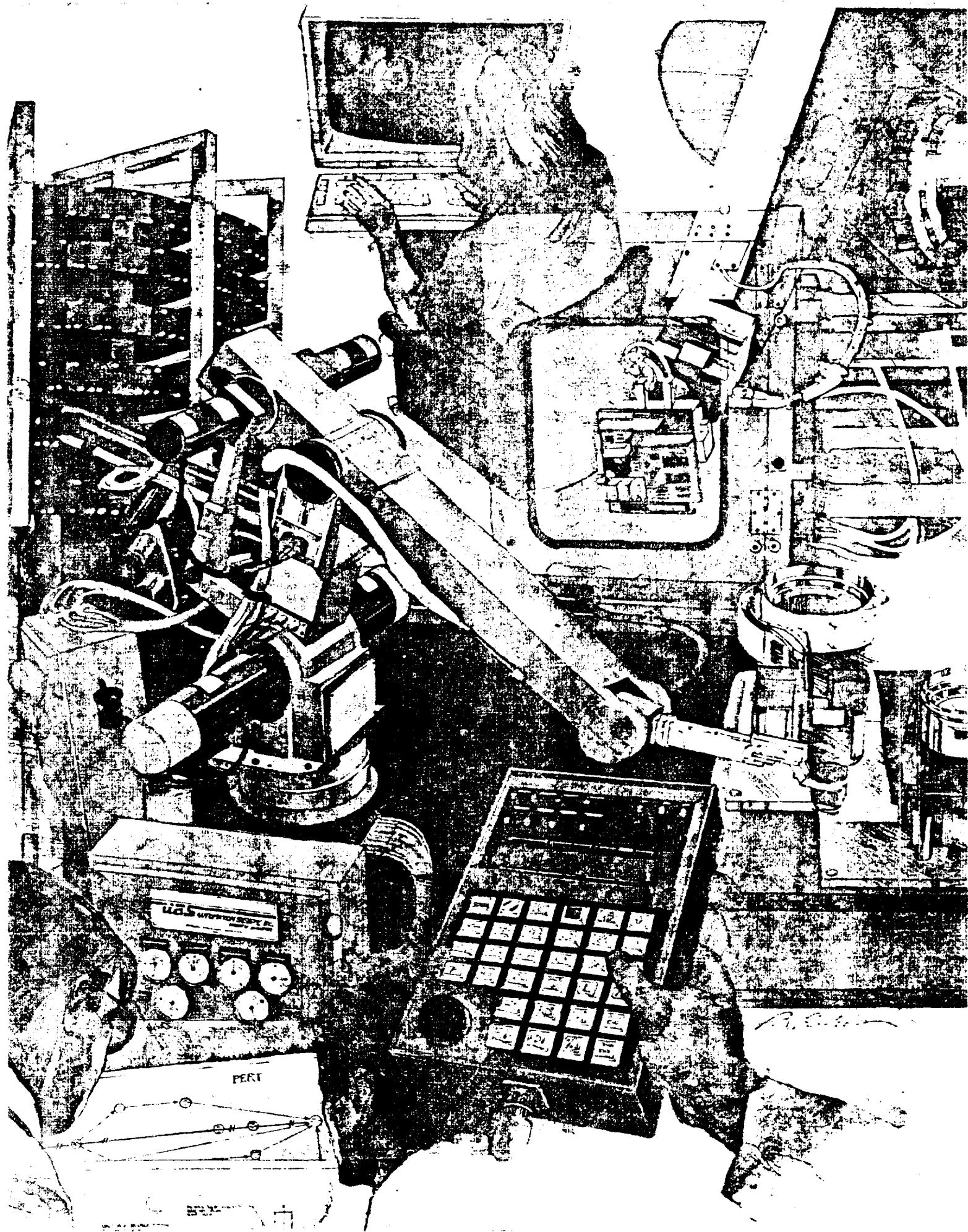
ELECTROSTATIC TESTING CHAMBER ROBOTIC STATION











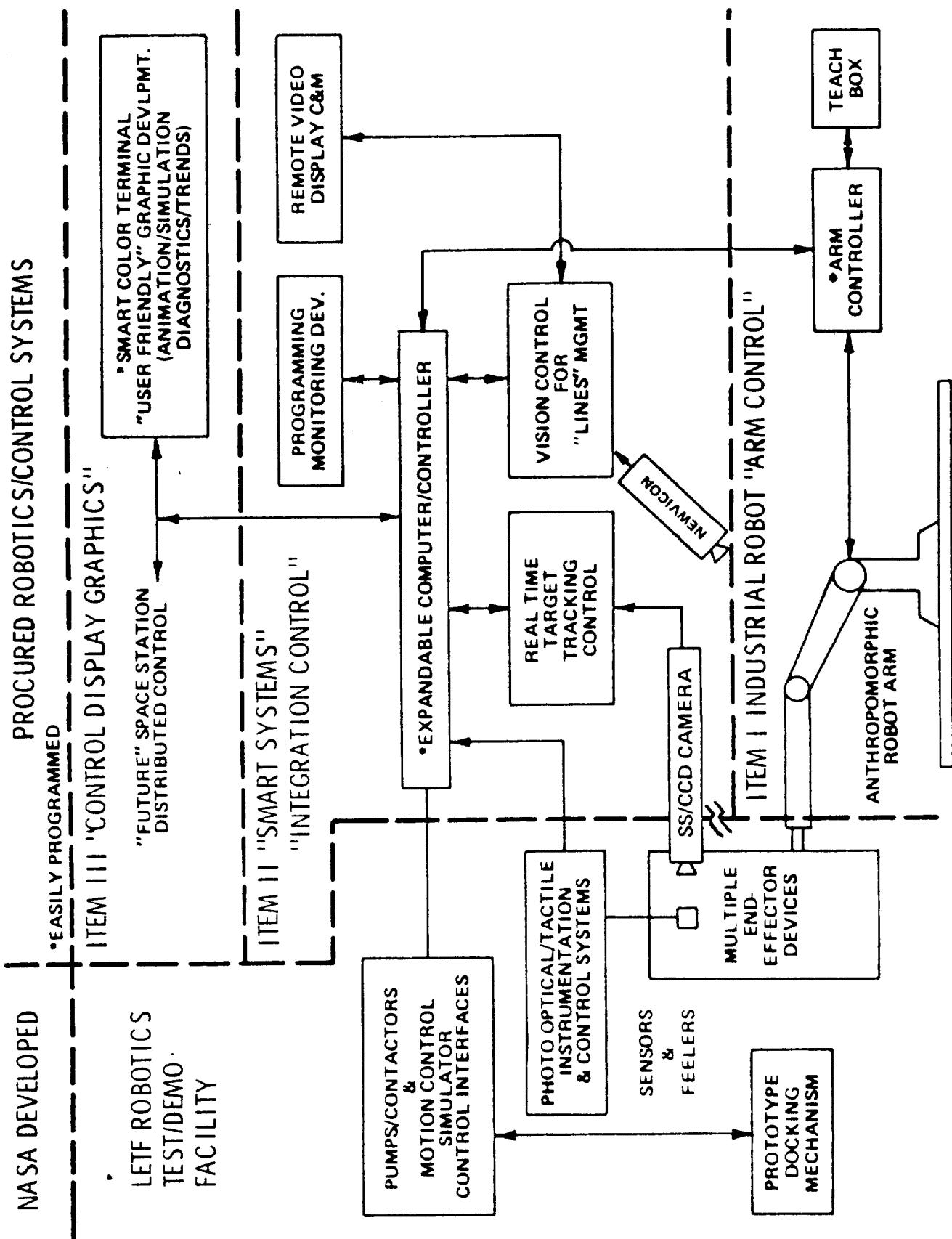


FIGURE 1. SYSTEM CONCEPT

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ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

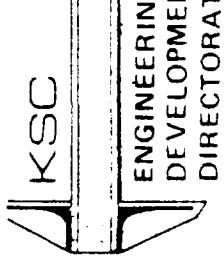
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ADAPTIVE ROBOTICS

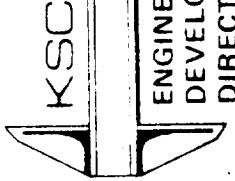
"PERFORMING OPERATIONS OTHERWISE BEYOND THE CAPABILITY OF THE ROBOT."

- COMMERCIAL ROBOTS TRADITIONALLY DO NOT ALLOW AN EASY AND EFFECTIVE MEANS TO INTEGRATE SENSORS WITH ROBOTS IN THE FORMATION OF FLEXIBLE SYSTEMS.
- WITHOUT THIS CAPABILITY, IT IS EXTREMELY DIFFICULT TO DEVELOP A SYSTEM IN WHICH ROBOT MOTION CAN BE CONTROLLED ADAPTIVELY IN REAL TIME.



ADAPTIVE ROBOTICS

- ASEA CONTRACT IS RESPONSIVE TO RFP REQUIREMENTS OF PROVIDING:
"REAL-TIME ADAPTIVE SERVO CONTROL & FEEDBACK MECHANISM INTEGRATION".
- IN ADDITION TO STATE-OF-THE-ART COMPUTERIZED TRACKING SYSTEM HARDWARE,
READILY EXPANDABLE FOR FUTURE DEVELOPMENT NEEDS; ASEA & ADAPTIVE
AUTOMATION IS PROVIDING SOFTWARE UTILITIES THAT WILL:
 - (1) PROVIDE PATH CONTROL (POSITION & ORIENTATION) OF ALL 6 AXES,
(NOT JUST POSITION OF THE END-EFFECTOR).
 - (2) ENABLE HIGHLY CONFIGURABLE TESTBED FOR SENSOR DEVELOPMENT.
 - (3) PROVIDE SYSTEM COORDINATION TO MAKE THE ROBOT, GRAPHICS AND
VISION CONTROLLERS APPEAR AS INTELLIGENT PERIPHERALS.



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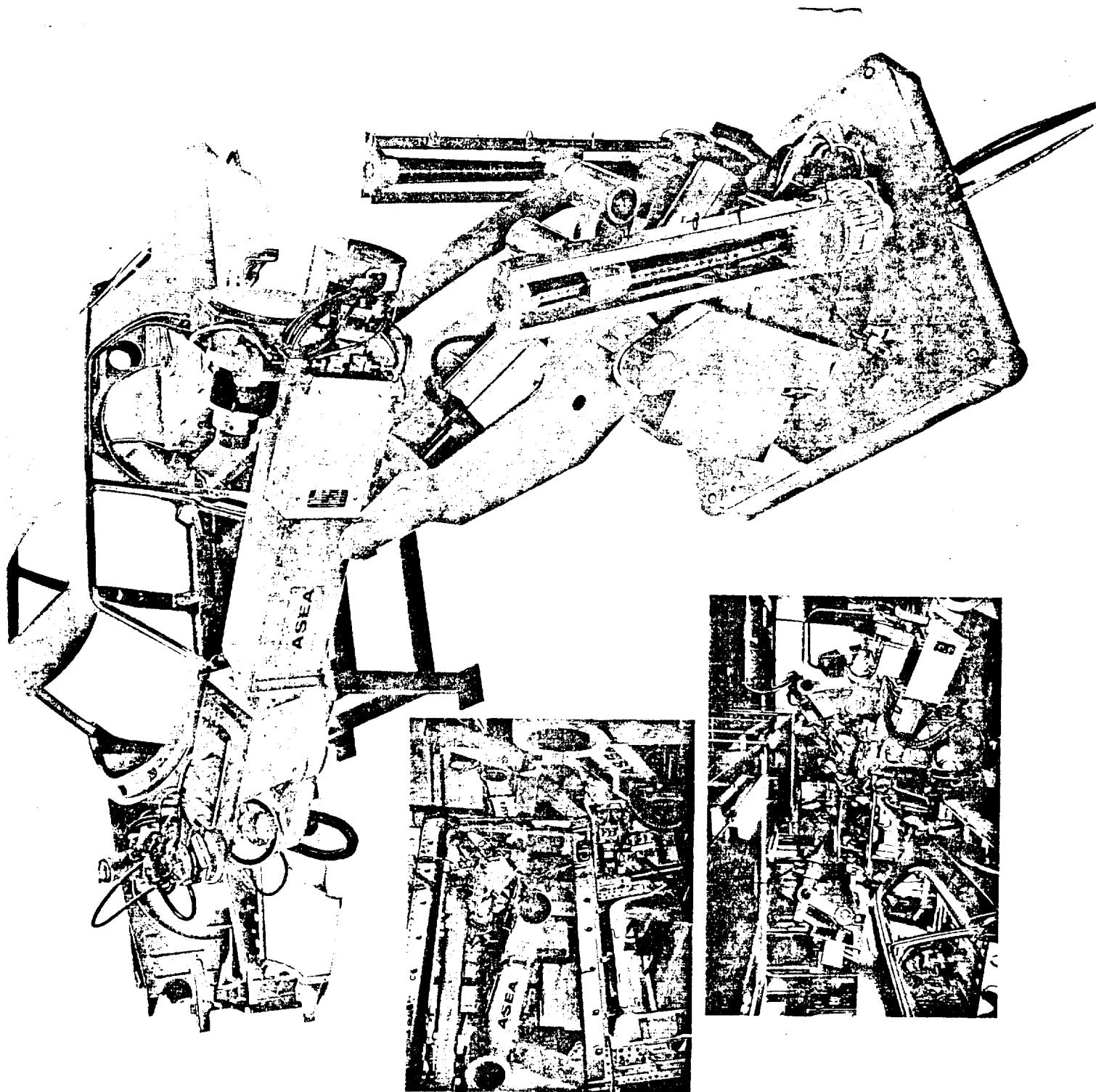
V. LEON DAVIS
MAY, 16, 1985

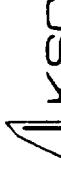
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ADAPTIVE ROBOTICS (CONT'D)

● USE OF SOFTWARE SUBROUTINE LIBRARIES DEVELOPED BY ADAPTIVE AUTOMATION:

1. HIGH-LEVEL **COMMUNICATION** SOFTWARE:
SUBSYSTEMS STATUS MONITORING
ROBOT PARAMETER EXCHANGE - BI DIRECTIONAL
PROGRAM UPLOAD/DOWNLOAD,
2. COORDINATE **TRANSFORMATION** SOFTWARE:
REDUCTION OF COMPUTATIONAL BURDEN
VISION SUBSYSTEM CALIBRATION
GRAVITY LOADING INACCURACY COMPENSATION,
3. COORDINATED PATH GENERATION SOFTWARE:
COMPLEX PATHS, TRAJECTORY, & VELOCITY MOTIONS;
4. LOW-LEVEL **DATA ACQUISITION** SOFTWARE:
DEVICE DRIVERS,
5. **SIGNAL PROCESSING** SOFTWARE,
6. **TOOL CONTROL** SOFTWARE, AND
7. **APPLICATION SPECIFIC** SOFTWARE:
SYSTEM DEMONSTRATION
ACCEPTANCE TESTING.





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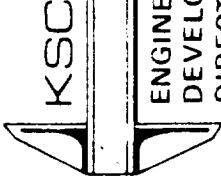
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

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SERVO-CONTROLLED ROBOTS

- USES STATE-OF-THE-ART SERVO TECHNOLOGY:
(RESPONSIVE CONTROL OF COMMAND, FEEDBACK & ERROR SIGNALS)
- MANIPULATION FLEXIBILITY (MULTIPLE AXIS POSITIONS)
- ACCURACY CAN BE VARIED ("ROUNDING OF CORNERS":
POINT-TO-POINT & CONTINUOUS MOTION)
- VARIABLE VELOCITY AND TRAJECTORY CONTROL
- SMOOTH MOTIONS (CONTROLLED MOVEMENT OF HEAVY LOADS)



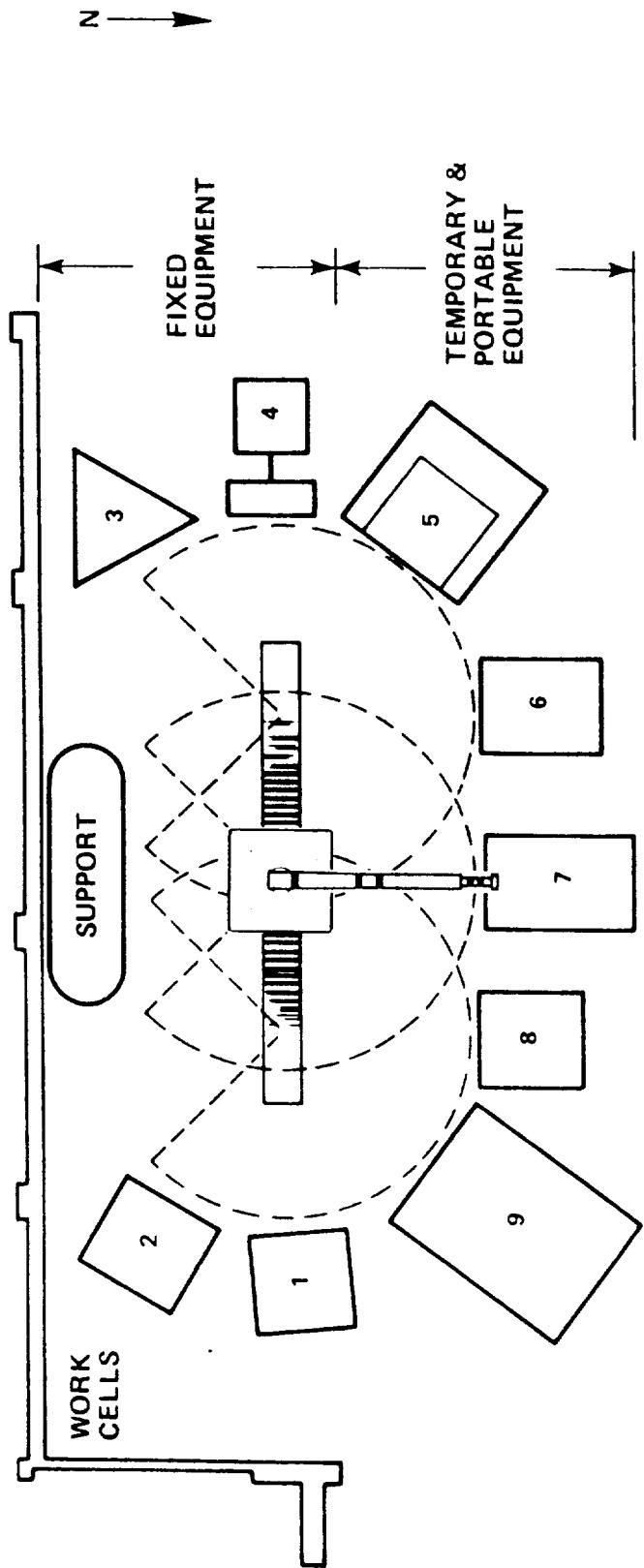
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DEVELOPMENT LABORATORY ACTIVITIES

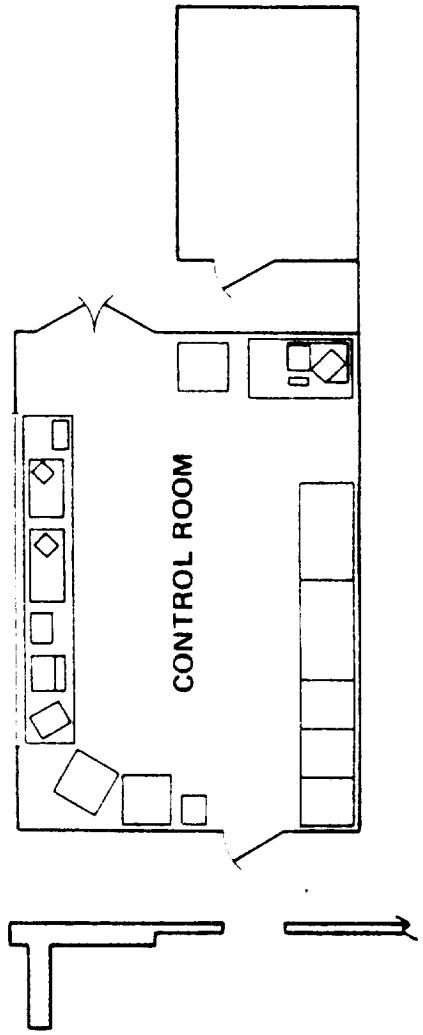
- LAB B (LETF)
 - LARGE ROBOTIC APPLICATIONS
 - HYPERGOLIC CART SERVICING
 - CRYOGENIC COUPLINGS
 - LARGE CONNECTORS/QD'S
 - TRACKING & DOCKING DEVELOPMENT
 - UMBILICAL PLATE DOCKING/INSERTION
 - PGHM DOCKING DEVELOPMENT
 - FUTURE KSC PECULIAR APPLICATIONS
 - INTERCENTER INTEGRATION PROJECTS
 - SMART SYSTEMS INTEGRATION
 - ROBOT CONTROLLER COORDINATION
 - TRACKING VISION SERVO CONTROL
 - COMPUTER/CONTROLLER SUBSYSTEMS INTEGRATION
 - SMART COLOR GRAPHICS
 - PROCESS ANIMATION, SIMULATION, DIAGNOSTICS & TRENDS
 - COMPLEX WORK CELL DEVELOPMENT

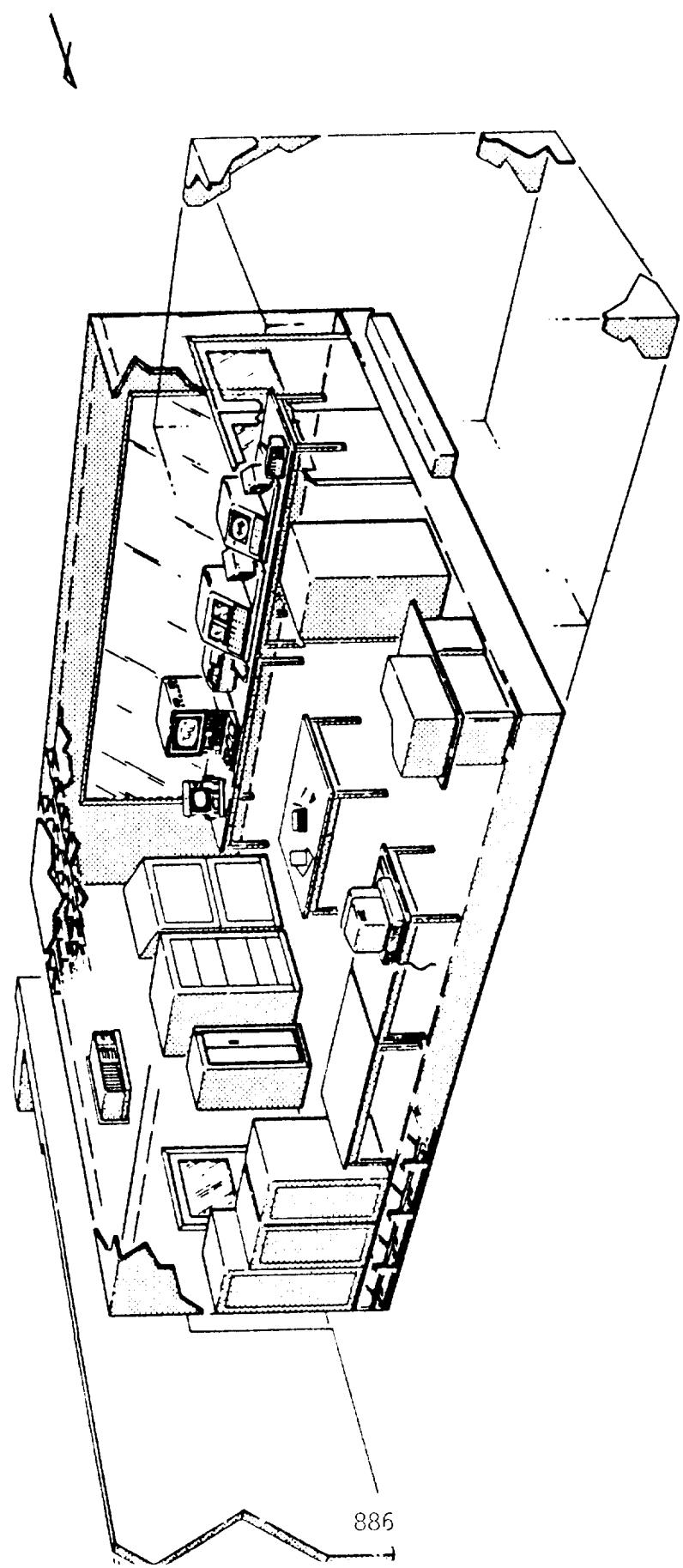


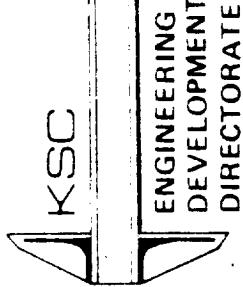
ROBOTIC DEVELOPMENT AREA

WORK CELLS:

1. HYPER. VALVE MANIP.
2. CRYOGENIC COUPLINGS
3. LARGE CONNECTORS / QD'S
4. TRACKING & DOCKING
5. UMBILICAL PLATES
6. FUTURE
7. APPLICATIONS
8. FUTURE
9. APPLICATIONS







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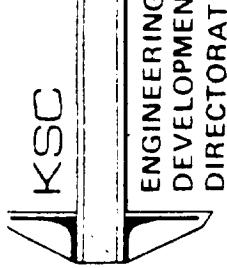
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

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REMOTE UMBILICALS

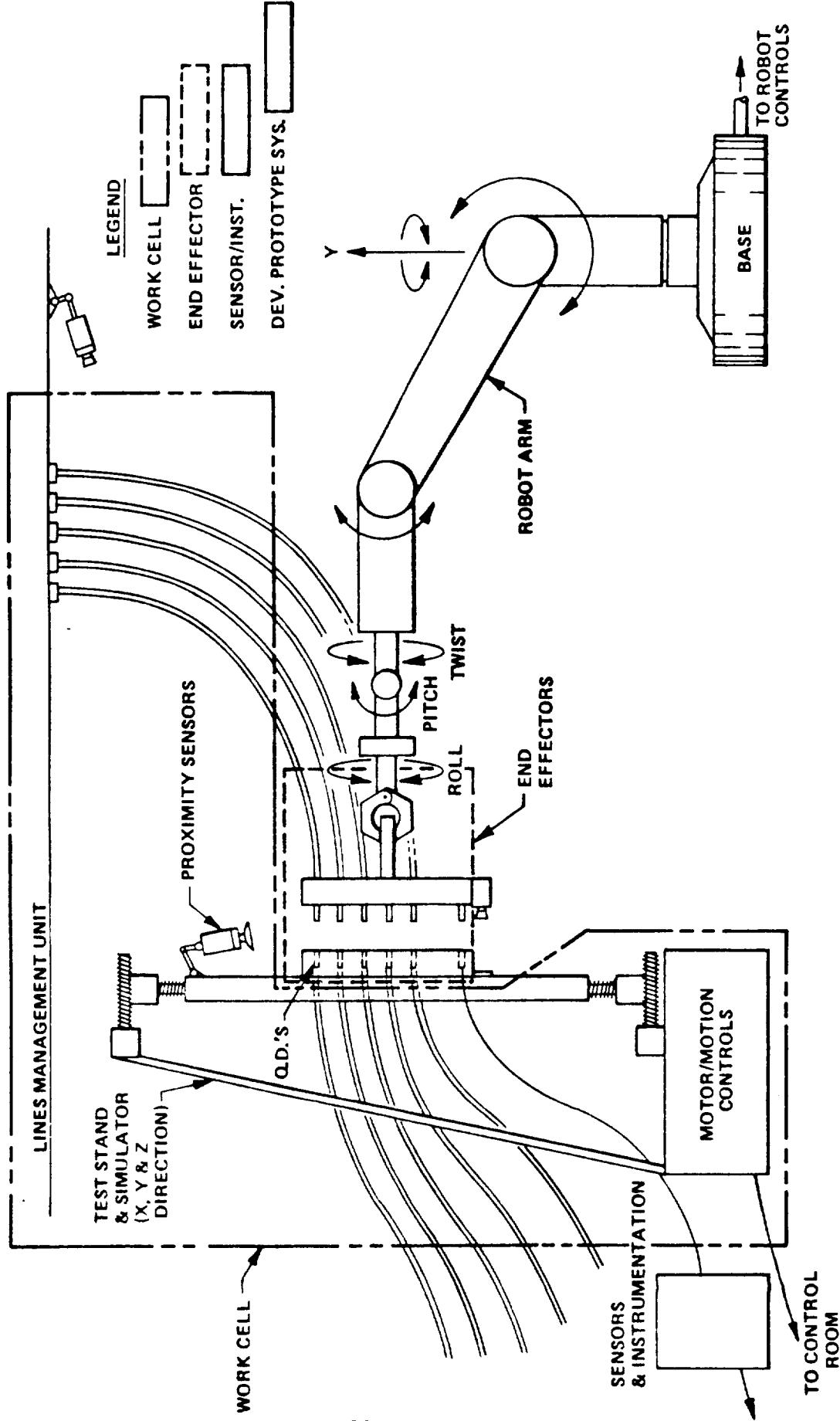
- WORK CELL
 - MECHANICAL/ELECTRICAL COMPONENTS.
 - STRUCTURES (PIPES, VALVES, CABLES, CLAMPS ETC).
 - LINE MANAGEMENT UMBILICALS.
- END EFFECTORS
 - UMBILICAL CONNECTOR (MECH/ELECT QD'S).
 - GRIPPERS.
 - INTEGRATED GANGED CONNECTOR PLATES.
- SENSORS & INSTRUMENTATION
 - LINEAR/ROTARY TRANSDUCERS.
 - FORCE/STRAIN SENSORS.
 - VISION/PROXIMITY FEEDBACK.

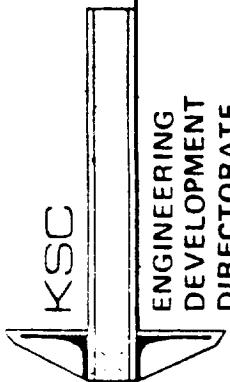


PROTOTYPE DEVELOPMENT SYSTEM

B. FERGUSON

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V. LEON DAVIS

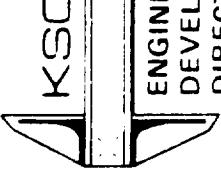
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OUTLINE

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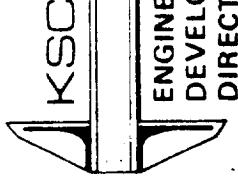
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APPLICATION OF ROBOTS

- 7/1/84 ARTICLE IN THE ORLANDO SENTINEL ENTITLED:
"STAR FADES FOR ROBOTICS INDUSTRY"

"THERE AREN'T ENOUGH PEOPLE OUT THERE
WITH THE EXPERIENCE TO
RECOGNIZE A GOOD APPLICATION
AND IMPLEMENT IT!"

VERN ESTES (ROBOTIC SYS. MGR.) GE AUTOMATION SYS. DIV.



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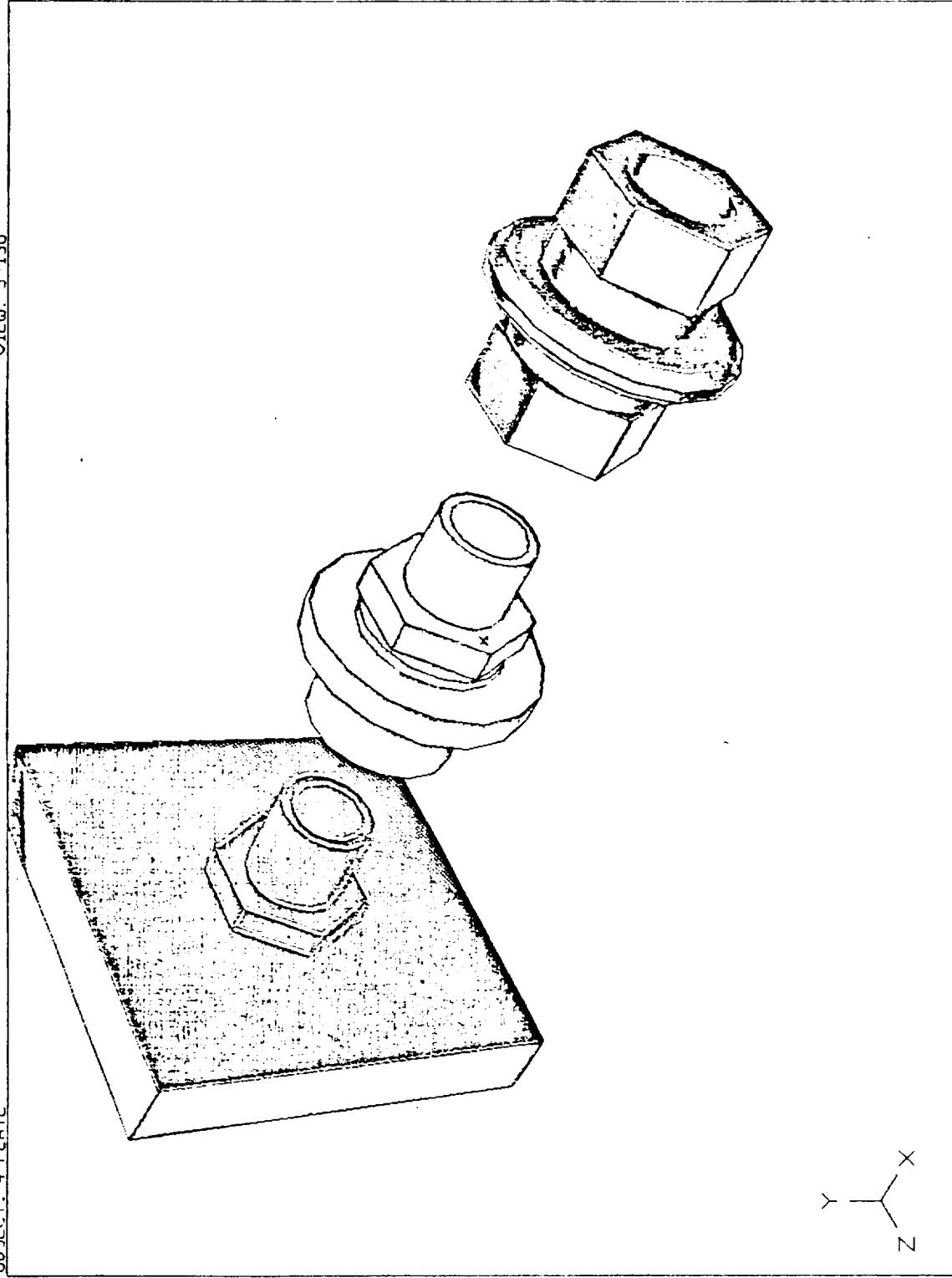
PLANNED KSC APPLICATIONS

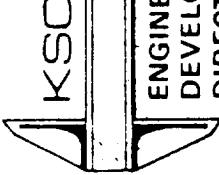
- ELECTRONIC SECURITY SYSTEM CARD TEST ROBOT
- ELECTROSTATIC TEST CHAMBER ROBOT
- LITHIUM HYDROXIDE CANNISTER RESERVICING PROTOTYPE
- LARGE WORK CELL DEVELOPMENT APPLICATIONS
- HYDRAZINE SERVICING CART
- CRYOGENIC COUPLINGS
- LARGE CONNECTORS / QD'S
- TRACKING & DOCKING DEVELOPMENT
- REMOTE UMBILICAL PLATE DOCKING / INSERTION
- OTHER HAZARDOUS, TIME CRITICAL, OR REPETITIVE
KSC PECULIAR APPLICATIONS

SDRC I-DEAS 2.5: Object Modeling (A)

10-MAY-85 09:27:33
UNITS-IN

DATABASE: HYDRO REDESIGN FOR ROBOT APPLICATION
TASK: OBJECT
BIN: 3-DIGNE
OBJECT: 4-PLATE



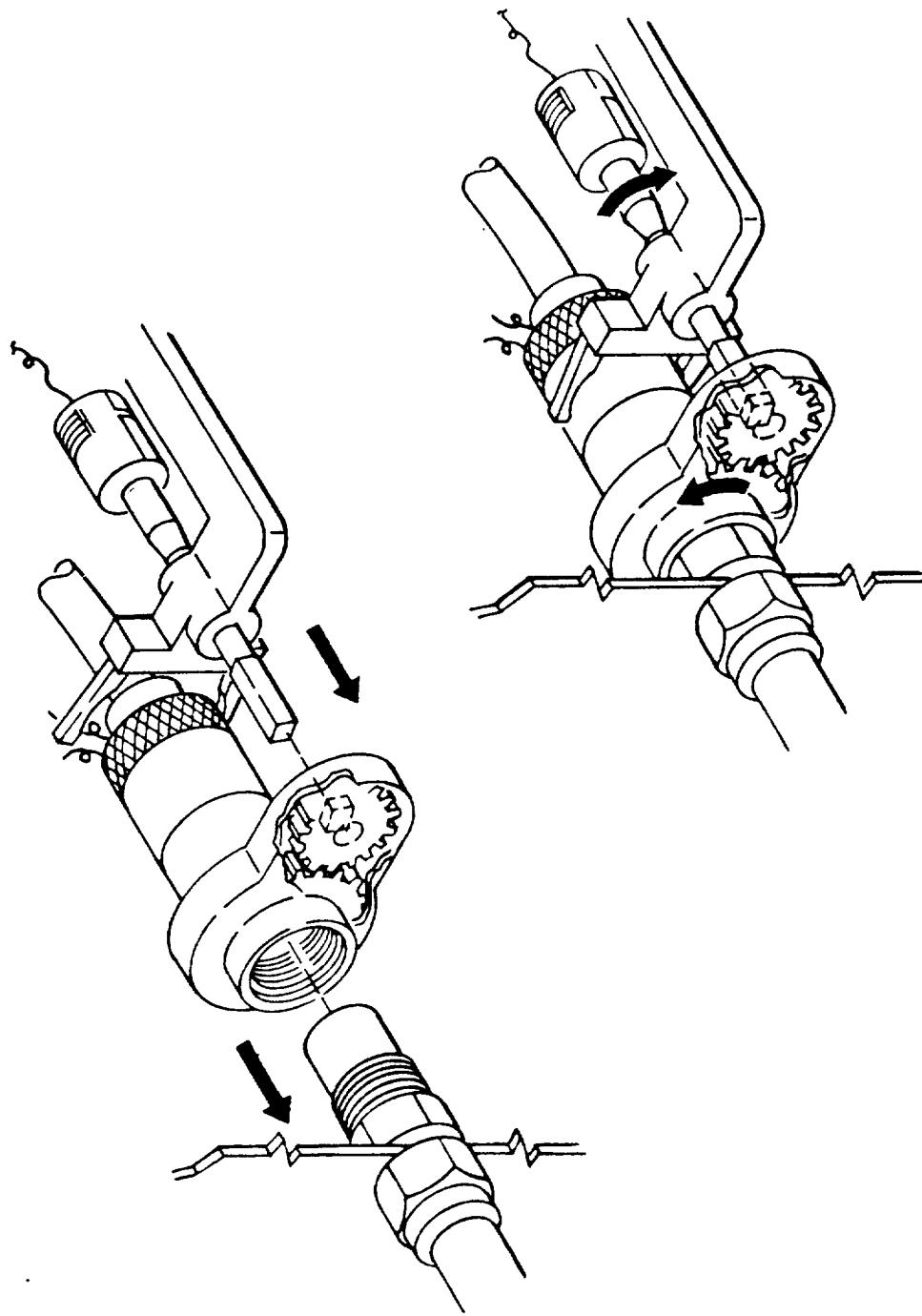


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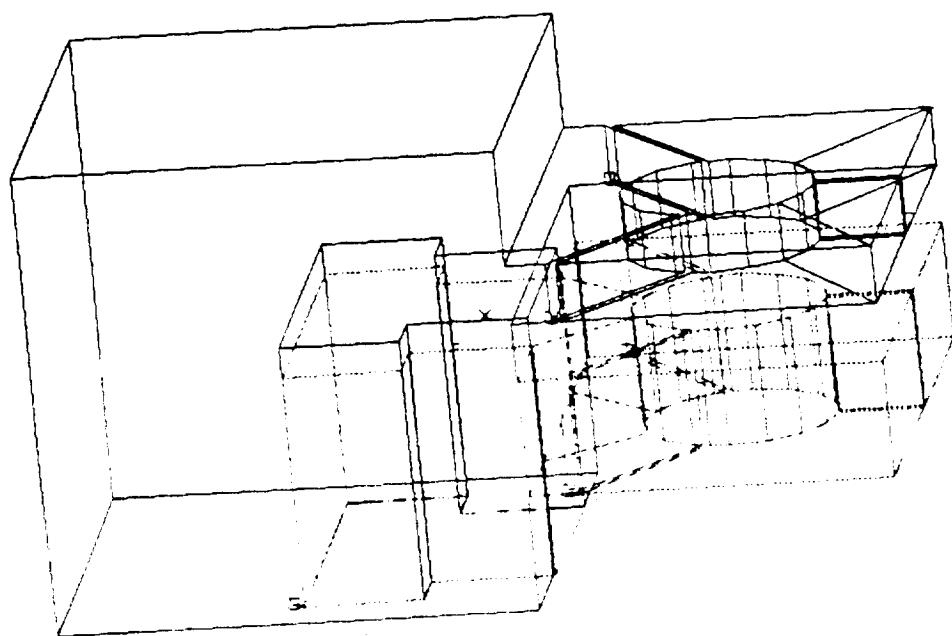


DATA BASE: GRIPPER FOR DD'S
ENTITY: GRAB - GRIPPER FOR DD'S
UNITS: IN
DISPLAY

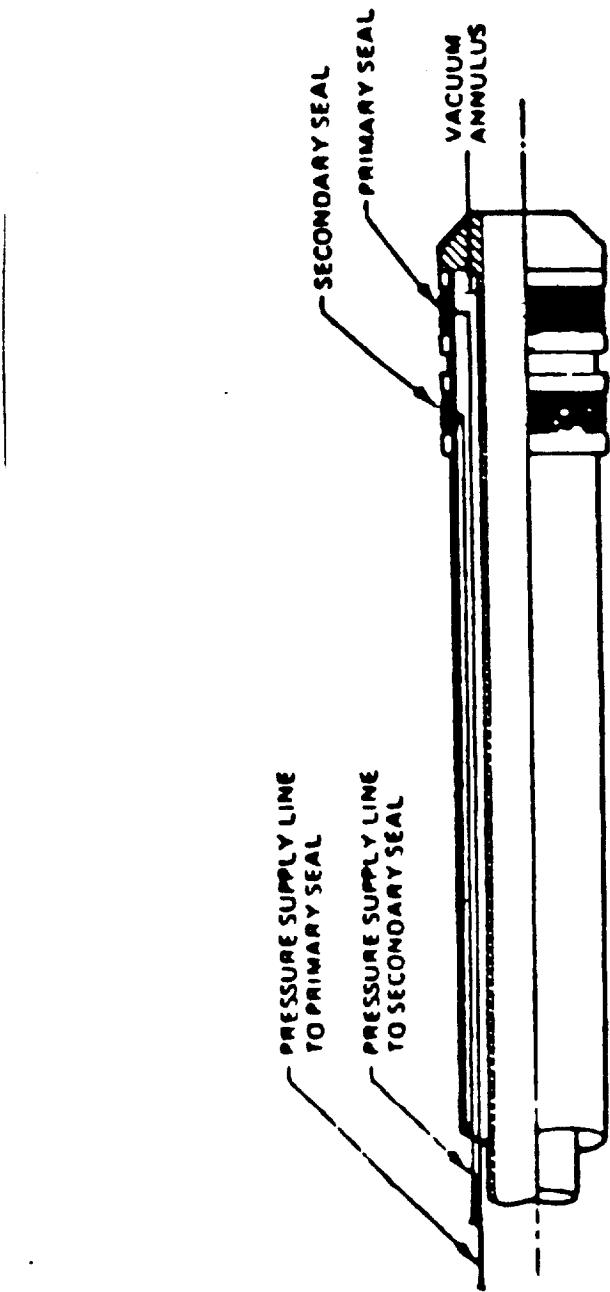
FIGURE 2.5: System Assembly (A)

3-APR-85 08:55:24

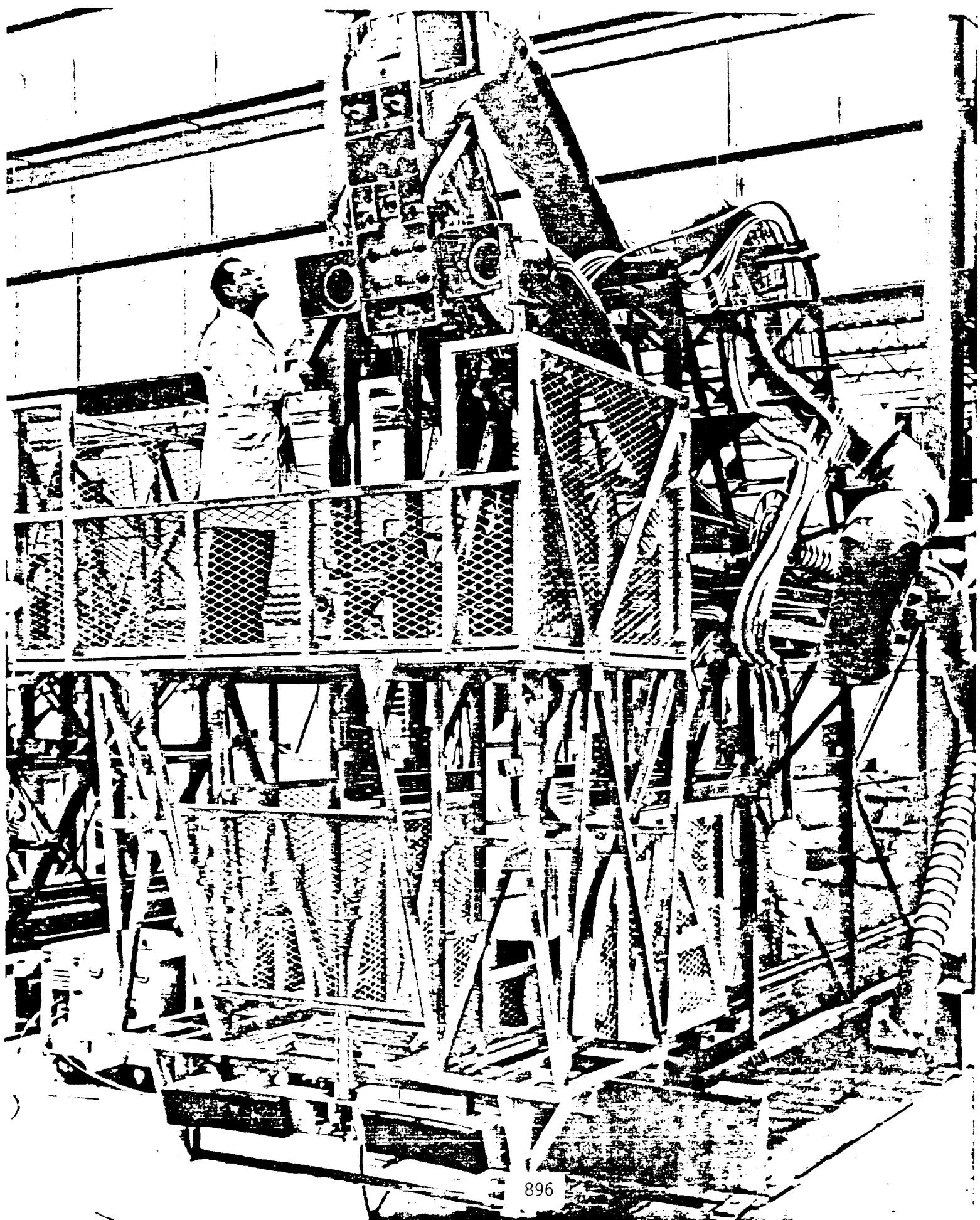
UNITS=IN
SYSTEM DISPLAY



X
Y
Z



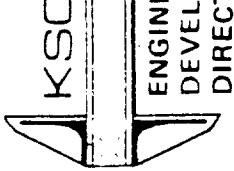
Male bayonet with inflatable seals.



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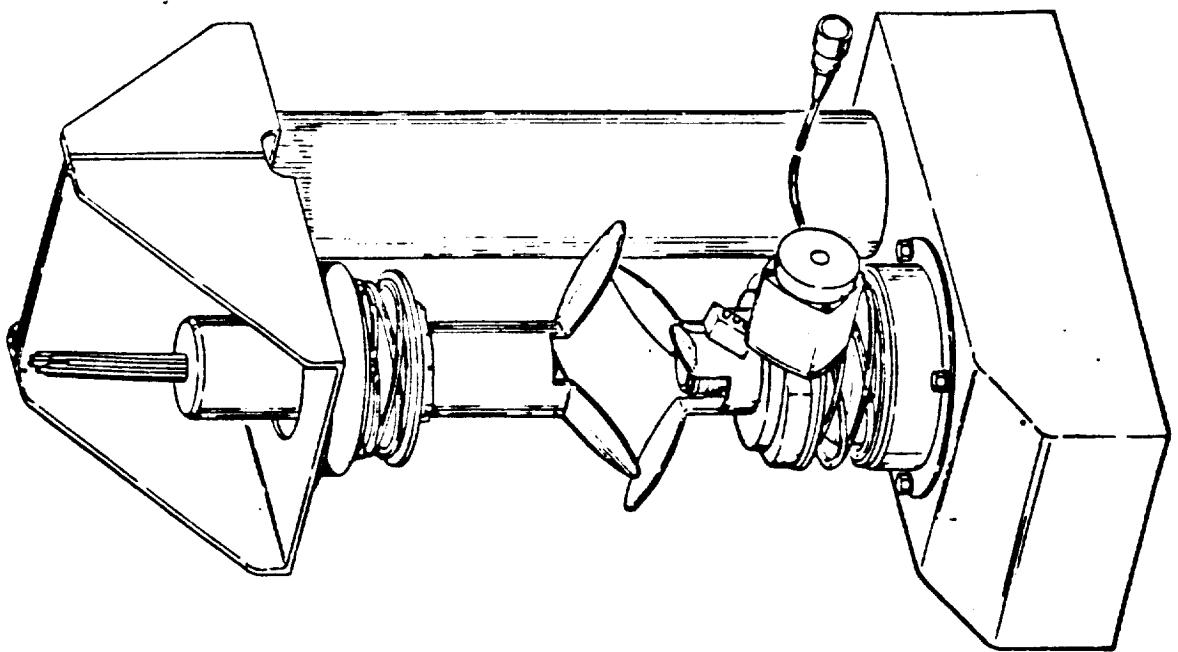
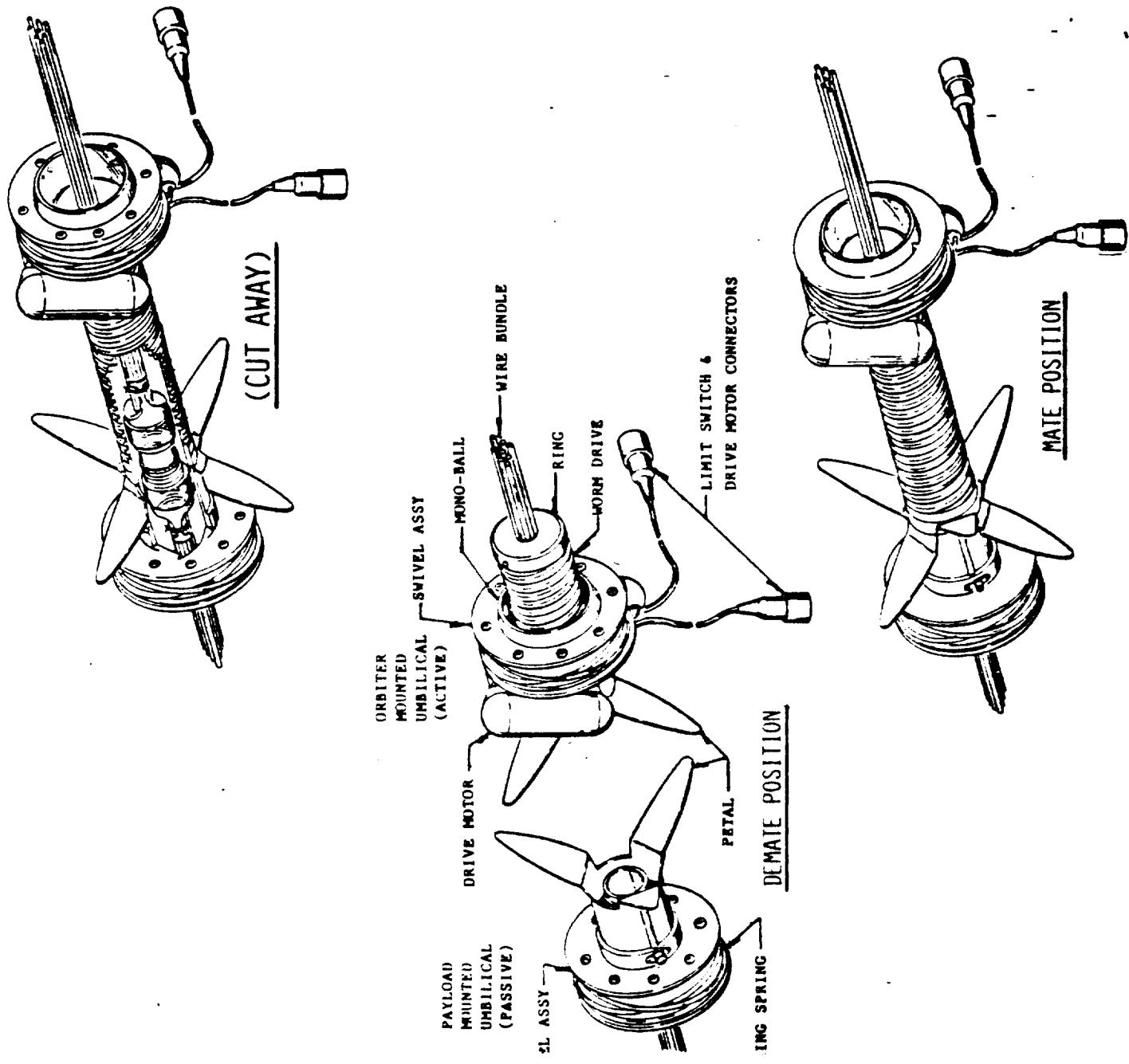
ROBOTICS APPLICATIONS DEVELOPMENT LABORATORY

V. LEON DAVIS
MAY. 16, 1985

INTERCENTER INTEGRATION

- ROCKWELL / (JSC) PROJECTS
 - ULTRASONIC PGHM DOCKING MECHANISM TESTING
 - REMOTE REMATEABLE COUPLING TESTING
- JSC PROJECTS
 - ECLS TEST BED COORDINATION
- MSFC PROJECTS
 - CONNICAL ELECTRICAL CONNECTORS
- POSSIBLE FUTURE INTERCENTER INTEGRATION
 - APPLICATION TESTING OF CENTER-PECULIAR WORK CELLS
 - KSC ENCOURAGES USE OF OUR ROBOTIC SYSTEM CAPABILITIES

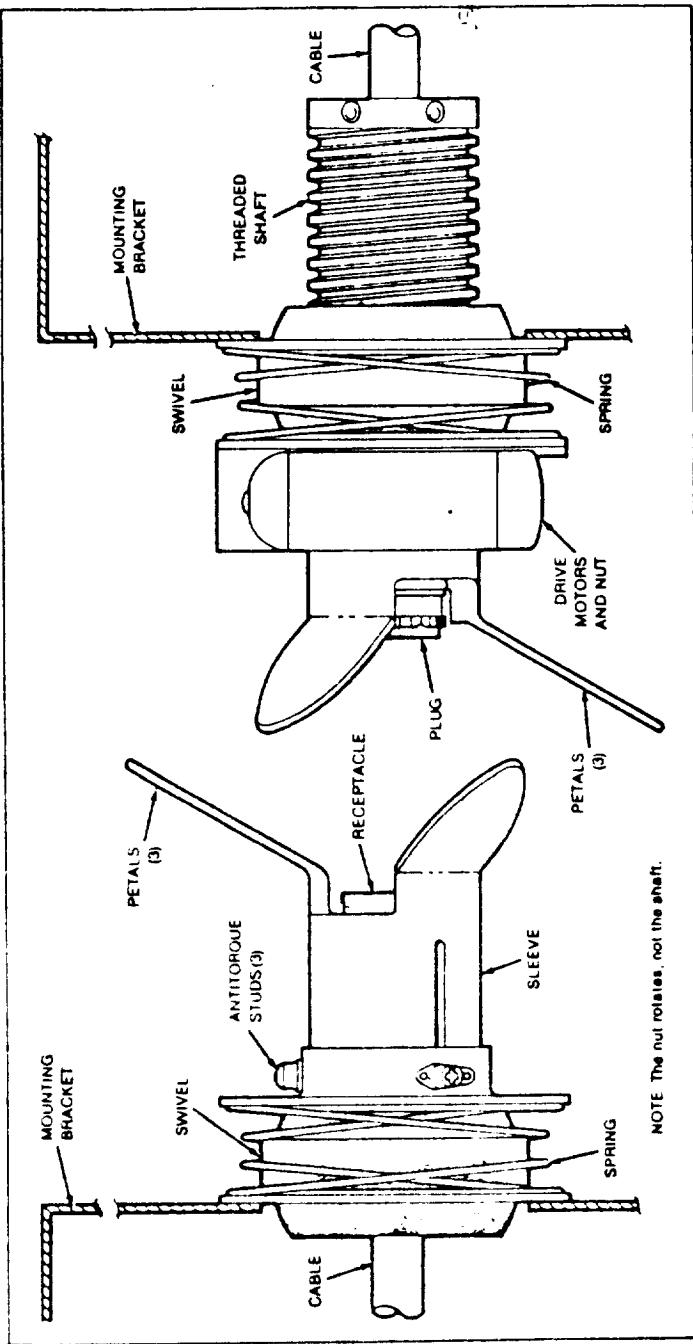
**KEMUI
REMOTEABLE UMBILICAL DISCONNECT**



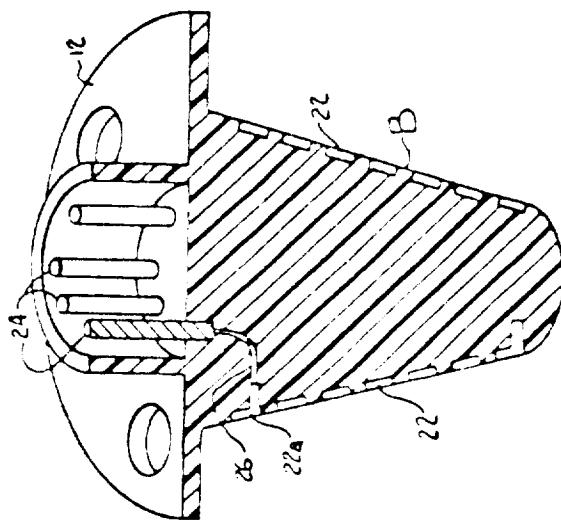
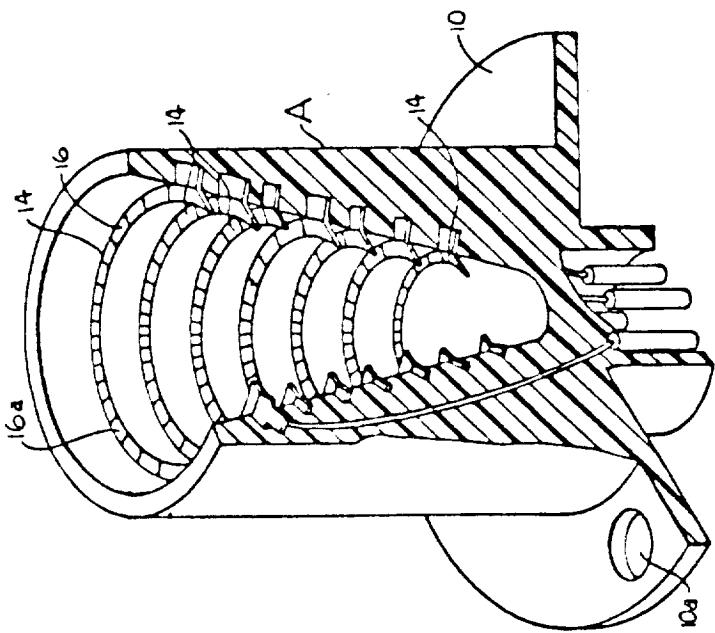
Remote Coupling of Electrical Connectors

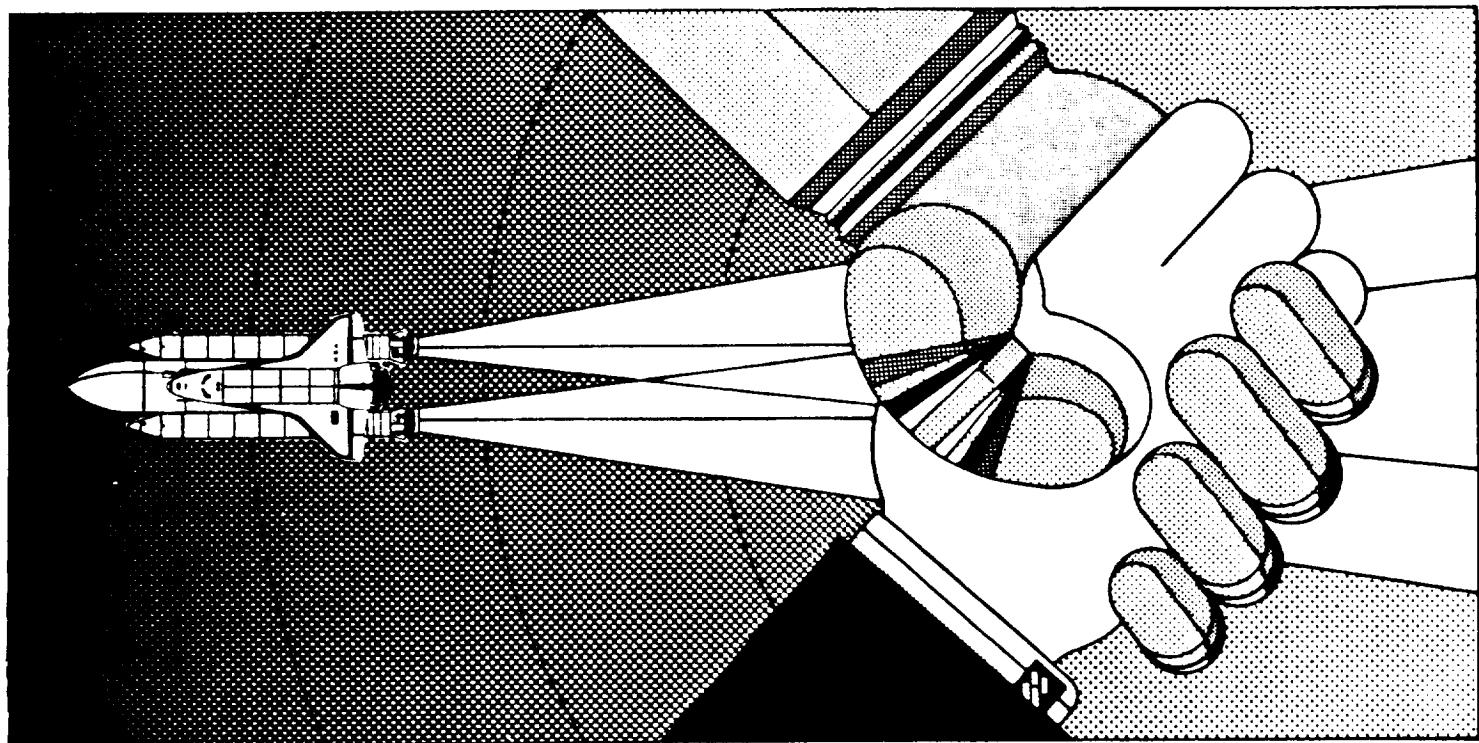
Device aligns a plug and receptacle axially and radially.

Lyndon B. Johnson Space Center, Houston, Texas



A Standard Multiple-Pin Plug and Socket are mounted in the mechanism. As the threaded shaft moves out from its mounting bracket (to the left in this view), the two sets of petals engage each other and correct misalignment. The misalignment is absorbed by the spring-mounted swivels.





**WORKING
WITH
ROBOTICS
TO
ACHIEVE
KSC'S
GOALS**

JOINT SESSION

SSIS + ATAC

WORKSHOPS

During this session, the plan is to have MDAC and TRW present informally on their results for approximately half of their allocated time, and the other half would be used for a question and answer period to allow an interaction between NASA and the Phase B contractors.

Chairman: A. Dula (SSIS Workshop Coordinator)

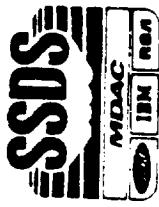
TIME	PRESENTATION	PRESENTER
1:30	Expert and Planning Systems	MDAC/TRW
3:30	Man/Machine Interface	MDAC/TRW
4:30	ATAC Summary	J. Erickson
5:00	Teleoperation/Robotics	J. Gilbert

THURSDAY AFTERNOON
MAY 16, 1985

AI AUTOMATION

904

NANCY LEG LANDI
FORD





WHY ARTIFICIAL INTELLIGENCE?

VGZ261

Generic Space Station Program Requirements

“Flight and Ground Systems Design Shall Consider Automation for Effective Resource Utilization. . . Subsystems Shall be Automated to the Fullest Extent Practical, Using Man’s Capability to Provide a Cost-Effective Alternative.”

RFP, C-3-3.3

Artificial Intelligence (AI) Can Advance the Automation of SSDS Functions

AI OPTIONS: AN INFORMATION BASE FOR TRADE STUDIES

		Related Trade Studies						
AI Options	AI Automation Function	Space-Qualified	High Order	Software and Test	Distributed Development	System Integ., Test & Verification	Crew Workstations	
		Automation	Computers	and Test	Management			
Hardware	X	X	X			X		X
Kernel Languages	X		X					
Support Environments		X			X			
Expert Systems		X			X	X	X	X
Image & Speech Recognition					X			
Natural Language						X		

1.6 ARTIFICIAL INTELLIGENCE — OPTIONS

1.6.1 Implementation Technology

- **LISP Machines**
- **Fifth-Generation Machines**
- **General Purpose Machines**
- **Space-Qualified Processors**

1.6.2 Applications

- **Expert Systems and Problem Solving**
 - Subsystem Control and Monitoring
 - System Configuration
 - Computer Programming and Computer-Assisted Instruction
 - Biomedical
 - Fault Detection/ Diagnosis/Correction
 - Planning, Scheduling, and Logistics
 - Modeling
 - Data Base Management
- **Kernel Languages**
 - LISP
 - PROLOG
 - Other
- **Support Environments**
 - LISP Machine Support Environments
 - Inference Engines
- **Image and Speech Recognition**
- **Natural Language Software**

HARDWARE

- **Ground Processors**
 - LISP Machines Available
- **Onboard Processors**
 - GP Processors as Target
 - LISP Processors Available 1987-1988
- **Advanced Processors Available 1988-1990s**
 - Specialized Inference Machines
 - PROLOG Processors
 - Fifth-Generation Parallel Processors

LANGUAGES

VGZ265

- LISP Now and in Near Future Most Popular Developmental Language
 - Common LISP Becoming a Standard
- PROLOG Popular in Europe and Japan
 - Fifth Generation
- Other Languages Suitable as Implementation Targets

SUPPORT ENVIRONMENTS

vGZ266

- LISP Machine Environments
 - Robust Software Development Tools
 - Networking Capabilities
- Inference Engines
 - Several Products Available
 - Production System "Tool Kits" Emerging
 - Product Choice Is an Application Design Decision

EXPERT SYSTEMS AND PROBLEM SOLVING

- Most Mature of the AI Technologies
- Suitable for Problems That
 - Are Complex, Evolutionary in Nature
 - Use Heuristic (Not Optimal) Solutions
- Capabilities Limited by Slowness of Response Time and Breadth of Knowledge
- Survey Provided of Existing Systems in Areas Applicable to the SSDS



IMAGE, SPEECH, AND NATURAL LANGUAGE

vGZ268

Image and Speech Recognition

- 2-D Vision Near-Term

- 3-D Vision Far-Term

- Speech Recognition More Promising
 - Large Vocabulary, Disconnected “Word” Recognition Near-Term
 - Large Vocabulary, Connected “Natural Language” Recognition Far-Term

Natural Language Software

- Robust, Application-Specific Products Emerging

AI (EXPERT SYSTEMS) TRADE STUDY

VGZ274

Task 1. Functions Data Base

- 1.0 Manage Customer/Oper**
- 1.1 Manage Real-Time Data**
- 1.1.1 Capture**
-
-

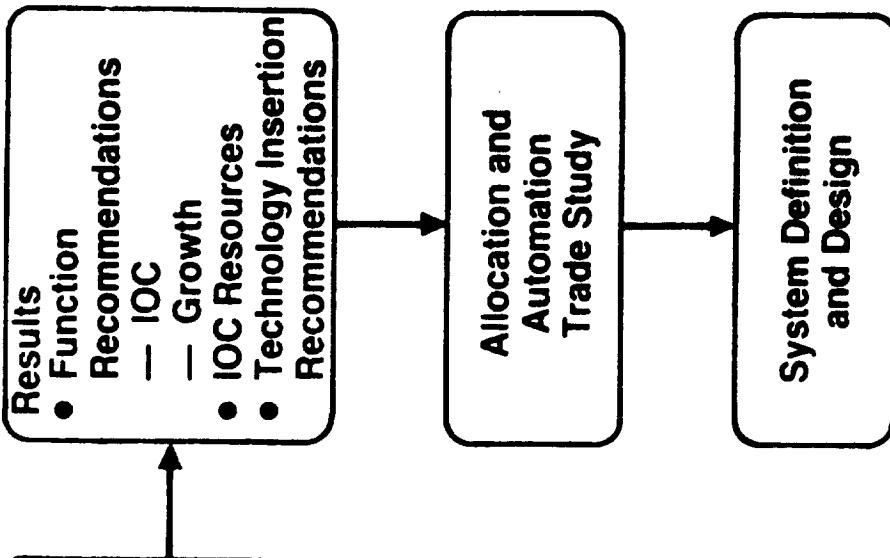
7.5.4 Configuration

Assess Merit: Expert System vs. Conventional

- Operational Risk
 - Safety
 - Response Time
 - Productivity/Performance
 - Complexity
 - Proven Systems
- Operational Cost
 - Reconfiguration
 - Growth
- Development Risk/Cost
 - Existence of Algorithms
 - Supporting Tools
 - Verification & Validation
 - Resource Availability
 - Schedule; Budget

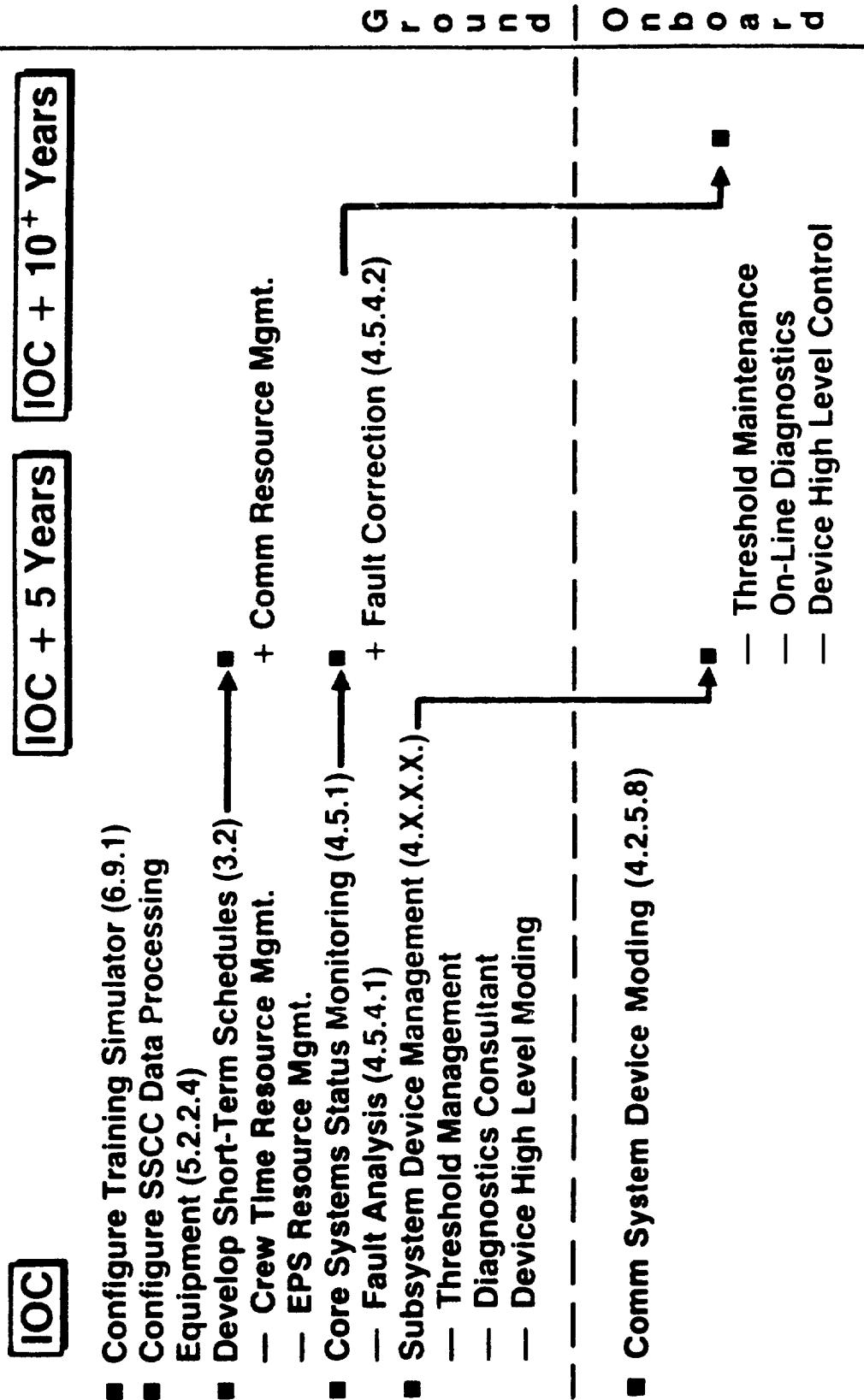
Information Base

- AI Options Survey
 - Government
 - Industry
 - University
- Team Experience
 - Aerospace
 - AI



PRELIMINARY RESULTS: IOC EXPERT SYSTEMS INTRODUCED

vGZ270





PRELIMINARY RESULTS: IOC + 5 YEARS EXPERT SYSTEMS INTRODUCED

vGZ271

IOC + 5 Years

- Configure SSDS Satellite Centers' Data Processing Equipment (5.3.2.4)

- Configure DHC Processing Equipment (5.4.2.4)

- Configure Development Support Facility Data Processing Equipment (5.2.2.4)

- Develop Software (6.10)
 - Automated Code Generation

- Facility Status Monitoring (5.X.2.5)

Facilities Device Management (5.X.2.6)

- Customer Systems Status Monitoring (4.5.2)

- OMV Checkout & Diagnostics (2.5.4.2)

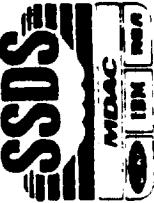
IOC + 10+ Years

G r o u p

Ob no a d

IOC + 10+ Years

- | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| G | r | o | u | n | p | O | a | b | p |
|---|---|---|---|---|---|---|---|---|---|
- Develop Typical Day Schedules (3.1)
 - Global Facilities Management (5.2.4)
 - Interpret Simulation Model Requests (6.1)
 - — — — —
 - Configure Flight Resource Data Processing Equipment (5.1.2.4)
 - Support OMV/OTV Operations (2.5.4/2.5.3)
 - OTV Checkout & Diagnostics (2.5.3.2)
 - Customer Payload Checkout/Service (2.5.5)



CONCLUSIONS

- Key Application Areas (Onboard and Ground) Exist for Expert Systems
 - Modeling/Configuring, Planning/Scheduling
 - High-Level Diagnostics
 - May Be of Lesser Value at the Subsystem Level
- Risks Exist
 - Speed at Which Expert System Technology Will Mature
- Anticipated Insertion of Expert System Technology Is Generally Not a Design Driver If
 - High-Level Control Functions (Manual or Automated) Are Segregated
 - Access Is Available to Necessary Data
- Minimize Risk at LOC
 - One, Prototype Expert System Onboard
 - Ground Expert Systems in Areas of High Operational Cost Savings
- Maturing Technology Plus Operational Experience Will Promote the Use of Expert Systems Onboard

FEEDBACK AND FOLLOW-ON

OVERVIEW COMMITTEE COMMENTS:

"... CONCERN THAT PERHAPS AN OVERLY CONSERVATIVE VIEW OF ARTIFICIAL INTELLIGENCE TECHNOLOGY FORECASTS MAY LIMIT THE DATA SYSTEM DESIGN CONCEPTS,"

- MASS MEMORY
- COMMUNICATIONS

"... NOT CLEAR THAT MDAC TEAM WAS FULLY COGNIZANT OF AND MAKING USE OF THE RESULTS COMING FROM THE AUTOMATION AND ROBOTICS STUDY"

STATUS:

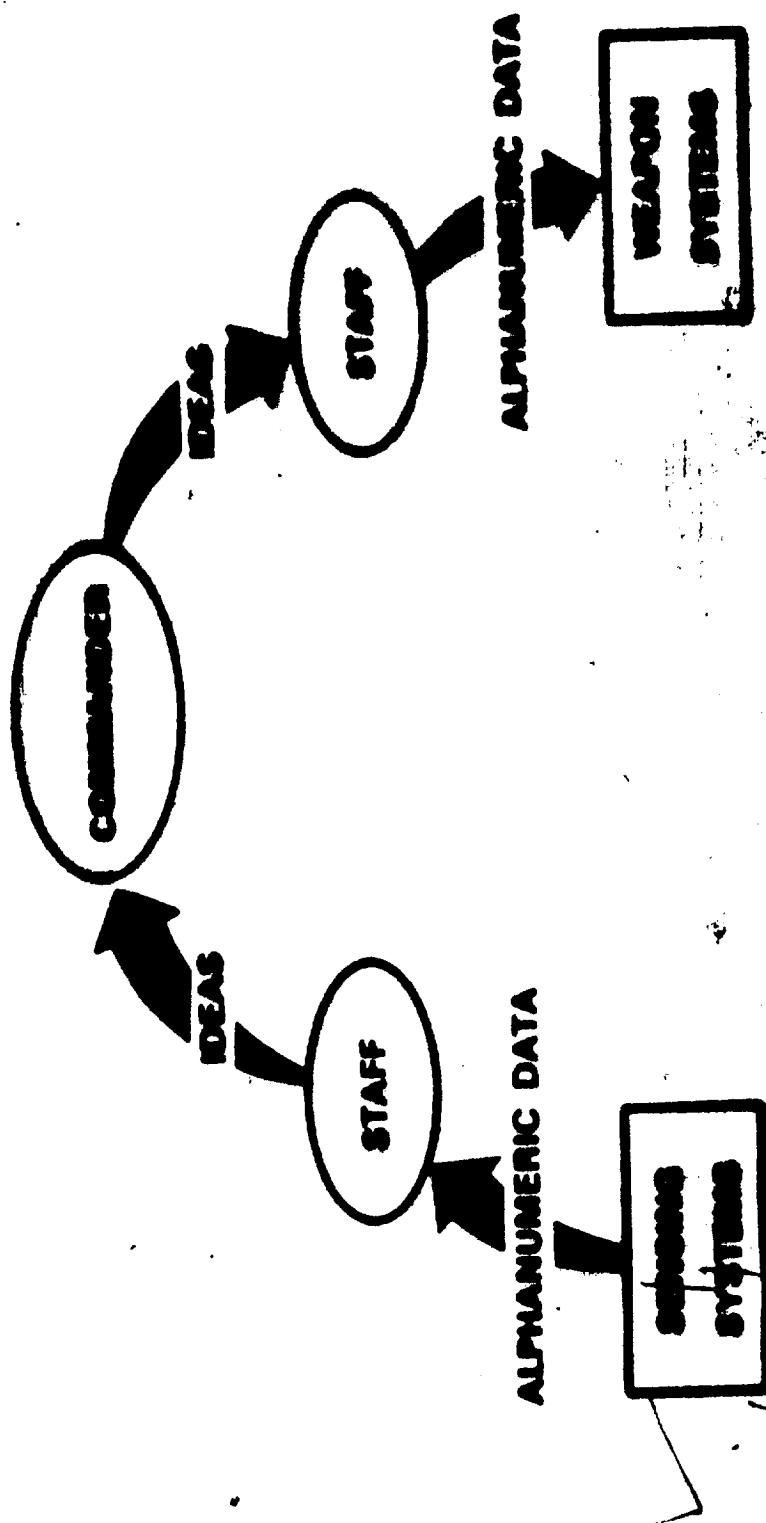
- TRADE STUDY SUSPENDED PENDING REVIEW OF ATAC TECHNICAL REPORT
 - IMPACTS SELECTION OF ONBOARD FUNCTIONS AND SSDS SIZING
 - No IMPACT TO SELECTION OF GROUND-UNIQUE FUNCTIONS (NOT ADDRESSED BY ATAC)
- NEED EXPERT SYSTEM SIZING DATA

**COMPLEX SYSTEMS
AND
INTELLIGENCE**

NOTE:

THIS SET
IS ALMOST
UNREADABLE

PAGES 919 - 931



Sundar
Kumar

Padma
Vibhushan

President
of India

HUMAN (CLASS A)		PARADISE - 2 (200 PRODUCTIONS)		PARADISE - 3 (213 PRODUCTIONS)	
GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	ALL
89%	95%	94%	80%	63%	75%
78%	69%	94%	70%	65%	71%
100%	95%	100%	95%	85%	97%

PRESCRIBER	ACCEPTABLE PRESCRIPTIONS, PERCENT
MYCIN	66
FACULTY 1	62.5
FACULTY 2	60
INFECTIOUS DISEASE FELLOW	60
FACULTY 3	57.5
ACTUAL THERAPY	57.5
FACULTY 4	55
RESIDENT	45
FACULTY 5	45
STUDENT	30

NEED IDENTIFIED BY O&M MANAGER

- 8500 CONTROL SETTINGS
- SHORTAGE OF EXPERTISE
- KNOWLEDGE AVAILABLE IN-HOUSE

DESIGN BASED ON MYCIN IDEAS

- IF-THEN RULES
- EXPLANATIONS IN ENGLISH
- KNOWLEDGE AND INFERENCE SEPARATE

EVOLUTION SIMILAR TO R1

- DEMONSTRATOR IN LAB: 75 RULES
- DEMONSTRATOR IN FIELD: 100 RULES
- DEMONSTRATOR AFTER 6 MONTHS: 200 RULES
- SIGNIFICANTLY REDUCES ENGINEERING LABOR
- SPEEDS UP TRAINING

- NEW RESPECT FOR HUMANS
- UNDERSTANDING OF EXPERT SYSTEMS
- EXPLOITATION OF LISP MACHINES
- FEAR OF AI WINTER
- CHUNKING VS. PARALLEL PROCESSING ISSUE

J. bel

for mule!

lives

111

926

10/16
J. bel
gravelled



CESA-ADEPT: ESC ANALYSTS COMMENTS

- "XEROX SOFTWARE APPEARED TO OFFER THE MOST POTENTIAL FEATURE FOR FUTURE INTELLIGENCE USES"
- "THE TIME INVOLVED TO MAKE ANALYTICAL DECISIONS CONCERNING SITUATION ASSESSMENT WAS GREATLY REDUCED AND THE GRAPHIC DISPLAY TO DEMONSTRATED SITUATIONS WAS EXCELLENT"
- "IT IS A GREAT ANALYST AID"
- "WILL RESULT IN A MORE NEAR-REAL TIME INTELLIGENCE ANALYSIS"
- "CONCEPT AND METHODOLOGY OF SITUATION ASSESSMENT WERE PRESENTED ACCURATELY"
- "WOULD MAKE FOR A GREAT BRIEFING 'BOARD' FOR UP-TO-DATE BATTLE SITUATION"

- MOST ENCOURAGING WAS THOUGHT PATTERNS IN SOFTWARE
- GREAT IMPROVEMENT OVER WHAT WE ARE USING
- DISPLAYS FUNCTIONS NECESSARY TO DO GOOD ANALYTICAL WORK

■ USAFE

- SOFTWARE HAS GREATEST POTENTIAL
- REPRODUCTION OF THOUGHT PROCESSES OF THE "PERFECT ANALYST"
- IS GREAT IDEA
- REPRESENTATIVE OF THE WAY I WOULD ARRIVE AT CONCLUSIONS

■ CENTCOM

- COULD BE INVALUABLE WHEN PERFECTED FOR REAL - TIME USE
- BETTER THAN THE PRESENT SYSTEM FOR INTELLIGENCE ANALYSIS
- JUST THE BEGINNING; MUCH MORE MONEY AND WORK NEEDED

■ SAC

- WOULD BE EXTREMELY VALUABLE TO PACAF INTELLIGENCE ANALYSTS
- NO COMPARISON, GREAT IMPROVEMENT OVER PRESENT METHODS

■ PACAF

- SOFTWARE HAS DEFINITE POTENTIAL
- WHEN / IF DEPLOYED WOULD BE AN INVULNERABLE TOOL

■ MAC

ADEPT WORKSTATION

NEED DEFINED BY INTELLIGENCE STUDIES

- PACE OF BATTLE VERSUS COGNITIVE LIMITS
- SPREAD IN OPERATOR CAPABILITIES
- EXCLUSIVE PROMISE OF AI

IMPORTANT LESSONS PROVIDED BY DEVELOPMENT

- VASTNESS OF SITUATION KNOWLEDGE
- LIMITS OF CURRENT TECHNOLOGY
- PRIMACY OF SYSTEM ENGINEERING

AI POTENTIAL CONFIRMED BY DEMONSTRATION

- ACCESSIBLE, INTELLIGIBLE, MALLEABLE KNOWLEDGE
- EXPLANATION OF CONCLUSIONS
- WHAT-IF CAPABILITY

SUMMARY

• • • • • SIGNIFICANTLY INFLUENCED BY

• • • • • MAINTENANCE LIMITED BY

• • • • • ROTE TASKS

• • • • • CAN BE OFFLOADED TO SMART SYSTEMS

• • • • • NEED TO BUILD GOOD SUPPORT SYSTEMS

• • • • • COMPETENT, ATTENTIVE DEPUTY - BUT
"ENGINEER"

• • • • • RESOURCES SYSTEM IN

• • • • • THIS WAY IT'S HELPFUL

• • • • • LEAVE NOONE OUT

• • • • • INTERFACE

• • • • • INTO EDUCATIONAL, PRACTICAL, AND
CONCRETE OPERATION

• •

USER INTERFACE ACTIVITY GROUPS

- REAL TIME COMMAND AND CONTROL; MANUAL FUNCTIONS, USUALLY TIME CRITICAL, PERFORMED BY GROUND OR SPACE STATION CREW (NOT PAYLOAD SPECIALISTS) TO CONTROL LIFE-THREATENING OR MISSION-THREATENING OPERATIONS
- PASSIVE MONITORING (MANY PROCESSES)
 - CONTINUAL ONGOING AUTOMATIC PROCESSES, TYPICALLY NOT OPERATOR-INITIATED
 - DUE TO NUMBER AND DURATION OF PROCESSES, NO OPERATOR ACTION REQUIRED TO MONITOR STATUS CHANGES
- INFORMATION STORAGE AND RETRIEVAL; NON-TIME-CRITICAL FUNCTIONS THAT REQUIRE INFORMATION TO BE ENTERED INTO OR RETRIEVED FROM DATA BASE

LARRY
M C LAUGHLIN
TRW

USER INTERFACE ACTIVITY GROUPS (Continued)

- COMPUTATIONAL SUPPORT; MATHEMATICAL DATA PROCESSING FUNCTIONS, INCLUDING COORDINATE TRANSFORMATIONS, CURVE FITTING, MATRIX MANIPULATION, AND CORRELATIONAL ANALYSIS
- PROCESS PLANNING AND SCHEDULING; FUNCTIONS TO SUPPORT PLANNING SERIES OF EVENTS, (i.e. AN OPERATION OR SCENARIO, TO BE CARRIED OUT AT A LATER TIME) ORDINARILY PERFORMED ON THE GROUND, BUT MAY BE DONE ABOARD THE SPACE STATION
- ACTIVE MONITORING (FEW PROCESSES) AUTOMATIC FUNCTIONS, LIMITED DURATION AND NUMBER, INITIATED AND MONITORED ACTIVELY BY THE USER AND ORDINARILY EXECUTED ONE AT A TIME

USER INTERFACE ACTIVITY GROUPS (Concluded)

- CONSTRUCT/DESIGN/CONFIGURE; DESIGN-ORIENTED FUNCTIONS ALLOWING OPERATOR TO CONFIGURE/CONSTRUCT A SYSTEM OR PAYLOAD, ACTIVITIES NOMINALLY PERFORMED ON GROUND BUT MAY BE DONE ABOARD SPACE STATION
- RECOVERY FROM AUTOMATIC PROCESS FAILURE; MANUAL INTERVENTION IN AUTOMATIC PROCESS TO RECOVER FROM FAILURE OR OTHERWISE ALTER OUTCOME, PAYLOAD SPECIALISTS MAY INTERVENE ONLY IN PROCESSES THAT INITIATED, WHILE NASA CREW MAY INTERVENE IN ANY
- HANDS-FREE EVA; FUNCTIONS PERFORMED BY CREW, WHICH, BECAUSE OF TASK OR ENVIRONMENTAL DEMANDS ON THE ASTRONAUT, REQUIRE NON-CONTACT TECHNIQUES FOR INTERACTING WITH SSDS

USER INTERFACE TRADEOFFS FOR REAL-TIME COMMAND AND CONTROL

SCORE	DIALOG OPTIONS
1243	Cont Voice
1214	Graph Tablet
1213	Discr Voice
1204	Qwerty Keybd
1194	Touch Panel
1164	Light Pen
1151	Joystick
1146	Mylar Panel
1128	Button
1112	Toggle Switch

SCORE	INPUT MEDIA OPTIONS
1093	Mouse
1077	Trackball
1063	Num Keypad
1028	Fingerpad
960	RF
893	Slide Switches
885	Dials
797	Sonic
773	Computer Vision

SCORE	OUTPUT MEDIA OPTIONS
963	Dig Panel
930	Soft Copy
807	Voice
774	Indic Lights
737	Sound
561	Hard Copy

USER INTERFACE TRADEOFFS FOR INFORMATION STORAGE AND RETRIEVAL

SCORE	DIALOG OPTIONS
683	Forms
671	Dir Manip
626	Cmd Lang
594	Menus
555	Nat Lang
553	Funct Keys
515	Q&A

SCORE	INPUT MEDIA OPTIONS
747	Button
737	Trackball
731	Toggle Switch
721	Finger Pad
651	Dials
641	Slide Switches
533	RF
441	Sonic
440	Computer Vision

SCORE	OUTPUT MEDIA OPTIONS
552	Dig Panel
505	Soft Copy
462	Voice
397	Indic Lights
397	Indic Lights
383	Hard Copy

USER INTERFACE TRADEOFFS FOR ACTIVE MONITORING (SINGLE PROCESS)

DIALOG OPTIONS		INPUT MEDIA OPTIONS		OUTPUT MEDIA OPTIONS	
SCORE		SCORE		SCORE	
785	Dir Manip	759	Disc Voice	679	Dig Panel
673	Menus	758	Mouse	664	Soft Copy
664	Cmd Lang	756	Trackball	485	Voice
662	Forms	738	Fingerpad	419	Indic Light
631	Funct Keys	641	Dials	412	Sound
593	Nat Lang	634	Slide Switches	400	Hard Copy
535	Q&A	547	RF		
		455	Sonic		
		433	Computer Vision		

USER INTERFACE TRADEOFFS FOR INTERACTIVE FAILURE RECOVERY

SCORE	DIALOG OPTIONS
824	Dir Manip
797	Cmd Lang
793	Nat Lant
752	Menus
685	Forms
677	Funct Keys
651	Q&A

SCORE	INPUT MEDIA OPTIONS
960	Trackball
954	Mouse
916	Fingerpad
916	Num Keypad
860	RF
824	Slide Switches
817	Dials
760	Sonic
690	Computer Vision

SCORE	OUTPUT MEDIA OPTIONS
932	Dig Panel
892	Soft Copy
754	Voice
710	Indic Lights
682	Sound
526	Hard Copy

USER INTERFACE TRADEOFFS FOR "HANDS FREE" OR EVA ACTIVITIES

SCORE	DIALOG OPTIONS
887	Nat Lang
801	Cmd Lang
650	Menus
590	Q&A

SCORE	INPUT MEDIA OPTIONS
1260	Cont Voice
1221	Discr Voice
1122	RF
939	Computer Vision
	(Other Input
	Media requires
	manual operation
	atmosphere)

SCORE	OUTPUT MEDIA OPTIONS
836	Dig Panel
821	Soft Copy
707	Voice
691	Indic Lights
670	Sound
467	Hard Copy

ATAC NASA AUTOMATION AND ROBOTICS

INFORMATION EXCHANGE WORKSHOP

MAY 13 – 17, 1985

Jon D. Erickson

NASA
Lyndon B. Johnson Space Center

NEW CHALLENGES AND A NEW ERA IN SPACE

- WE MUST MAKE USE OF THE NEW TECHNOLOGIES BECOMING AVAILABLE TO ASSURE EFFECTIVE UTILIZATION OF OUR RESOURCES.
- WE MUST MEET THE CHALLENGE OF INTERNATIONAL COMPETITION IN SPACE (A CHALLENGE WE WELCOME!).
- WE MUST ESTABLISH A PERMANENT MANNED PRESENCE IN SPACE.
- WE MUST MOVE FROM AN ERA CENTERED PRIMARILY ON SPACE EXPLORATION TO AN ERA WHICH ALSO OPTIMIZES THE COMMERCIAL USES OF SPACE.

CONGRESSIONAL MANDATE

JULY 18, 1984 - PUBLIC LAW 98-371

"THAT THE ADMINISTRATOR SHALL ESTABLISH AN ADVANCED TECHNOLOGY ADVISORY COMMITTEE IN CONJUNCTION WITH NASA'S SPACE STATION PROGRAM AND THAT THE COMMITTEE SHALL PREPARE A REPORT BY APRIL 1, 1985, IDENTIFYING SPECIFIC SPACE STATION SYSTEMS WHICH ADVANCE AUTOMATION AND ROBOTIC TECHNOLOGIES, NOT IN USE IN EXISTING SPACECRAFT, AND THAT THE DEVELOPMENT OF SUCH SYSTEMS SHALL BE ESTIMATED TO COST NO LESS THAN 10 PER CENTUM OF THE TOTAL SPACE STATION COSTS."

ADVANCING AUTOMATION AND ROBOTICS TECHNOLOGY FOR THE SPACE STATION AND FOR THE U.S. ECONOMY

THE PURPOSE OF THIS ATAC REPORT IS TO:

- MAKE RECOMMENDATIONS TO NASA BY WHICH THE AGENCY WILL SATISFY THE CONGRESSIONAL INTENT TO HAVE NASA IDENTIFY AND ADVANCE THE STATE-OF-THE-ART IN AUTOMATION AND ROBOTICS TECHNOLOGIES FOR USE IN THE SPACE STATION AND TO BENEFIT THE U.S. ECONOMY
- DOCUMENT, IN A SINGLE CONVENIENT SOURCE, IMPORTANT CONSIDERATIONS IN AUTOMATION AND ROBOTICS, SPECIFICALLY:
 - NASA SPACE STATION ENGINEERING AND PROGRAMMATIC ASPECTS
 - THE RECOMMENDATIONS OF THE ACADEMIC AND INDUSTRIAL COMMUNITY
 - DESCRIPTIVE AND BACKGROUND MATERIAL ON THE RELEVANT TECHNOLOGY
 - CASE STUDIES OF APPLICATIONS OF ADVANCED AUTOMATION AND ROBOTICS
 - TECHNOLOGY PROJECTIONS AND RESEARCH RECOMMENDATIONS
- PROVIDE GUIDANCE TO NASA SPACE STATION PROGRAM MANAGERS, TO PROSPECTIVE CONTRACTORS, AND TO NASA ASSOCIATE ADMINISTRATORS ON THE DEFINITION AND DEVELOPMENT OF ADVANCED AUTOMATION FOR THE SPACE STATION

ADVANCING AUTOMATION AND ROBOTICS TECHNOLOGY FOR THE SPACE STATION AND FOR THE U.S. ECONOMY (CONCLUDED)

- DOCUMENTATION OF THE AUTOMATION STUDY RESULTS IS PROVIDED AS FOLLOWS:
 - THE EXECUTIVE OVERVIEW (VOL. I), WHICH PROVIDES A SYNOPSIS OF THE MAJOR FINDINGS OF THE STUDY AND ESTABLISHES NASA RECOMMENDATIONS FOR THE NECESSARY ACTIONS
 - THE TECHNICAL REPORT (VOL. II), WHICH PROVIDES:
 - SOME GENERAL BACKGROUND TO FAMILIARIZE THE READER WITH THE TECHNOLOGIES AND POTENTIAL OF AUTOMATION AND ROBOTICS
 - THE SPACE STATION DESIGN CONSIDERATIONS OF IMPORTANCE
 - THE STATE OF THE TECHNOLOGY AND NEEDED ADVANCES
 - THE GUIDANCE TO BE GIVEN TO POTENTIAL SPACE STATION CONTRACTORS SO THEIR EFFORTS WILL RESULT IN A PLAN FOR ADVANCING THESE TECHNOLOGIES
 - CONSIDERATIONS FOR TECHNOLOGY TRANSFER TO U.S. INDUSTRY AND FOR SPACE COMMERCIALIZATION
 - THE CAL SPACE REPORT, WHICH PROVIDES THE FINDINGS AND RECOMMENDATIONS OF THE AUTOMATION AND ROBOTICS PANEL
 - REPORTS OF AEROSPACE CONTRACTOR CONCEPTUAL DESIGN STUDIES FOR REPRESENTATIVE FUNCTIONS
 - REPORT BY SRI INTERNATIONAL OF A TECHNOLOGY ASSESSMENT

AUTOMATION AND ROBOTICS A&R TECHNOLOGY

- ROBOTICS, TELEOPERATORS, AND SENSORS
- EXPERT SYSTEMS
- HUMAN FACTORS AND HUMAN-MACHINE INTERFACES
- PLANNING SYSTEMS
- VOICE RECOGNITION AND NATURAL LANGUAGE UNDERSTANDING
- COMPUTER VISION
- AUTONOMOUS SYSTEM DESIGN AND VERIFICATION
- RELATIONAL DATA BASES
- DISTRIBUTED PROCESSING
- FAULT TOLERANCE
- COMPUTER TECHNOLOGY
- SOFTWARE ENGINEERING AND VERIFICATION

BENEFITS TO THE SPACE STATION

IN MEETING THE NEEDS WITH AUTOMATION

IN EVOLVING OPTIMUM MAN/MACHINE MIX

- MEET INCREASED PRODUCTIVITY REQUIREMENTS
- LOWER COST OF OPERATIONS
- INCREASE FLEXIBILITY IN SUPPORTING INNOVATION
- ACHIEVE AUTONOMY IN SPACE, REDUCING GROUND OPERATIONS
- IMPROVE MISSION RELIABILITY
- PERFORM TASKS UNSUITED TO HUMANS ALONE
- REDUCE HAZARDS

ATAC RECOMMENDATIONS FOR SPACE STATION AUTOMATION AND ROBOTICS

85-03-009

BASIC

1. AUTOMATION AND ROBOTICS SHOULD BE A SIGNIFICANT ELEMENT IN THE SPACE STATION PROGRAM.
 2. THE INITIAL SPACE STATION SHOULD BE DESIGNED TO ACCOMMODATE FUTURE MAJOR EVOLUTION AND GROWTH IN A&R.
 3. THE INITIAL SPACE STATION SHOULD UTILIZE SIGNIFICANT ELEMENTS OF A&R TECHNOLOGY.
 4. CRITERIA FOR THE INCORPORATION OF A&R TECHNOLOGY SHOULD BE DEVELOPED AND PROMULGATED.
 5. VERIFICATION OF THE PERFORMANCE OF AUTOMATED AND ROBOTIC SYSTEMS SHOULD BE STRESSED, INCLUDING TERRESTRIAL AND SPACE DEMONSTRATIONS TO VALIDATE TECHNOLOGY FOR SPACE STATION USE.
 6. USE SHOULD BE MADE OF TECHNOLOGY DEVELOPED FOR INDUSTRY AND GOVERNMENT.
 7. AUTOMATION TECHNIQUES SHOULD BE USED TO ENHANCE NASA'S MANAGEMENT CAPABILITY.
 8. NASA SHOULD PROVIDE THE MEASURES AND ASSESSMENTS TO VERIFY THE INCLUSION OF A&R IN THE SPACE STATION PROGRAM.
- IF AUGMENTED
9. THE INITIAL SPACE STATION SHOULD UTILIZE AS MUCH AUTOMATION AND ROBOTICS TECHNOLOGY AS TIME AND RESOURCES PERMIT.
 10. THE EVOLUTIONARY STATION SHOULD ACHIEVE, IN STAGES, A VERY HIGH LEVEL OF ADVANCED AUTOMATION.
 11. AN AGGRESSIVE PROGRAM OF LONG-RANGE TECHNOLOGY ADVANCEMENT SHOULD BE PURSUED RECOGNIZING AREAS NASA MUST LEAD, LEVERAGE, OR EXPLOIT.
 12. A VIGOROUS PROGRAM OF TECHNOLOGY TRANSFER TO U.S. INDUSTRIES AND R&D COMMUNITIES SHOULD BE PURSUED.
 13. SATELLITES AND THEIR PAYLOADS ACCESSIBLE FROM THE SPACE STATION SHOULD BE DESIGNED, AS FAR AS POSSIBLE, TO BE SERVICED AND REPAIRED BY ROBOTS.

ATAC RECOMMENDATIONS (CONTINUED)

-
1. AUTOMATION AND ROBOTICS SHOULD BE A SIGNIFICANT ELEMENT IN THE SPACE STATION PROGRAM
 - A MEDIUM FOR PROMOTING A&R IN THE NATION
 - A PROGRAM-WIDE CONCERN, EQUAL IN IMPORTANCE TO SAFETY AND RELIABILITY
 - THE SUBJECT OF SPECIFIC R&D WORK
 2. THE INITIAL SPACE STATION SHOULD BE DESIGNED TO ACCOMMODATE EVOLUTION AND GROWTH IN AUTOMATION AND ROBOTICS
 - SYSTEM ARCHITECTURE SUPPORTIVE OF EVOLVING A&R TECHNOLOGY INCLUDING
 - A DATA SYSTEM SUPPORTIVE OF AI AND ROBOTICS
 - A DATA SYSTEM WITH RESERVE CAPACITY
 - CAD/CAE REPRESENTATIONS AND DESIGN RATIONALE IN THE DATA BASE
 - FLEXIBILITY TO INCORPORATE NEW HARDWARE
 - USE OF STANDARD HARDWARE, ESPECIALLY CONNECTORS
 - USE OF STANDARD MARKING TECHNIQUES
 - USE OF STANDARD PROGRAMMING LANGUAGES
 - USE OF EXPERT SYSTEMS
 - SENSORS FOR SYSTEM SELF-MONITORING
 - ONBOARD ACCESS TO DATA BASES
 - PROVISION FOR ROBOT MOBILITY
 - PROVISION FOR INTELLIGENT CONTROL DEVICES (HUMAN CONTROL A LAST RESORT)
 - CHOOSE CONTRACTORS FOR PHASES C AND D SENSITIVE TO A&R POTENTIAL
 3. THE INITIAL STATION SHOULD UTILIZE SIGNIFICANT ELEMENTS OF A&R TECHNOLOGY
 - CONSIDER ALL APPLICATIONS AVAILABLE AT TIME OF PDR
 - PROVIDE SUFFICIENT EMPHASIS TO PROMOTE FUTURE GENERAL-PURPOSE SYSTEMS
 - CONDUCT A SERIES OF DEMONSTRATIONS
 - AN INSPECTION ROBOT
 - A MOBILE "GO-FER" ROBOT (ASTRONAUT APPRENTICE)
 - AN AI-ENHANCED CONTROL DEVICE

ATAC RECOMMENDATIONS (CONTINUED)

- EMBED DEMONSTRATIONS IN A REALISTIC ENVIRONMENT
 - INVOLVE ASTRONAUTS EARLY AND PROVIDE MANUAL OVERRIDES TO BUILD CREW CONFIDENCE
 - SPECIFIC GOALS ARE LISTED (BY NO MEANS AN EXHAUSTIVE LIST)
4. CRITERIA FOR THE INCORPORATION OF A&R TECHNOLOGY SHOULD BE DEVELOPED AND PROMULGATED WITH A FOCUS ON
- PRODUCTIVITY
 - ANNUAL OPERATING COSTS
 - POTENTIAL FOR TRANSFER BACK TO EARTH
 - MINIMIZATION OF RISKS
 - RELIABILITY
5. VERIFICATION OF THE PERFORMANCE OF NEW TECHNOLOGY SHOULD BE STRESSED, INCLUDING TERRESTRIAL AND SPACE DEMONSTRATIONS TO VALIDATE THE TECHNOLOGY FOR SPACE STATION USE, RECOGNIZING
- GAPS IN CURRENT UNDERSTANDING
 - INTERACTIONS AMONG SUBSYSTEMS
6. MAXIMUM USE SHOULD BE MADE OF TECHNOLOGY DEVELOPED FOR INDUSTRY AND GOVERNMENT, QUALIFIED FOR SPACE USE, SUCH AS
- ADAPTATION OF INDUSTRIAL ROBOTS
 - CONSIDERATION OF DARPA PRODUCTS
 - A COMMERCIAL APPROACH

ATAC RECOMMENDATIONS (CONTINUED)

7. AUTOMATION TECHNIQUES SHOULD BE USED TO ENHANCE NASA'S MANAGEMENT CAPABILITY BY
 - USE OF CAD/CAM/CAE
 - USE OF OFFICE AUTOMATION
 - IMPLEMENTATION OF AN ELECTRONIC TECHNICAL AND MANAGEMENT INFORMATION SYSTEM
 8. NASA SHOULD PROVIDE THE MEASURES AND ASSESSMENTS TO VERIFY THE INCLUSION OF A&R IN THE SPACE STATION PROGRAM
 - FOCUS ON QUANTITATIVE GOALS AGAINST WHICH PROGRESS CAN BE MEASURED
- FURTHER, GIVEN AN AUGMENTED PROGRAM
9. THE INITIAL SPACE STATION SHOULD USE AS MUCH A&R TECHNOLOGY AS TIME AND RESOURCES PERMIT, VIA
 - ACCELERATED R&D AND TESTING
 - MORE COMPLETE PROVISION FOR NEW DEVELOPMENTS
 - ADDITIONAL DEMONSTRATIONS - E.G., AN EV ROBOT TO REPLACE PARTS
 10. AN EVOLUTIONARY STATION SHOULD ACHIEVE, IN STAGES, A VERY HIGH LEVEL OF ADVANCED AUTOMATION BY PROVIDING FOR
 - FACILE INTRODUCTION OF NEW TECHNOLOGY
 - AUTONOMOUS OPERATION AS THE EVENTUAL NORM
 - MINIMUM FLIGHT AND GROUND CREW INVOLVEMENT IN HOUSEKEEPING
 - A NATURAL (I.E., VOICE) HUMAN/MACHINE INTERFACE

ATAC RECOMMENDATIONS (CONCLUDED)

11. AN AGGRESSIVE PROGRAM OF LONG-RANGE TECHNOLOGY ADVANCEMENT SHOULD BE PURSUED, RECOGNIZING AREAS IN WHICH NASA MUST LEAD, PROVIDE LEVERAGE FOR, OR EXPLOIT DEVELOPMENTS. THIS PROGRAM WOULD
 - SEEK BREAKTHROUGHS TO FLEXIBLE, GENERAL-PURPOSE SYSTEMS AND DEVICES
 - SOLICIT IDEAS FROM ENTREPRENEURS
12. A VIGOROUS PROGRAM OF TECHNOLOGY TRANSFER TO U.S. INDUSTRIES AND R&D COMMUNITIES SHOULD BE PURSUED WITH
 - PRIORITY TO ORGANIZATIONS CONTEMPLATING COMMERCIAL SPACE ACTIVITIES
 - DUE REGARD FOR EXPLORATION OF JOBS
13. SATELLITES AND THEIR PAYLOADS ACCESSIBLE FROM THE SPACE STATION SHOULD BE DESIGNED, AS FAR AS POSSIBLE, TO BE SERVICED AND REPAIRED BY ROBOTS

IOC A&R APPLICATIONS GOALS

- ELECTRICAL POWER CONTROLLERS ENHANCED BY EXPERT SYSTEMS FOR:
 - LOAD DISTRIBUTION AND SWITCHING
 - SOLAR ARRAY ORIENTATION
 - TREND ANALYSIS
 - FAULT DIAGNOSIS
- GUIDANCE, NAVIGATION, AND CONTROL EXPERT SYSTEMS FOR:
 - STATION ATTITUDE CONTROL
 - EXPERIMENT POINTING
 - ORBITAL MAINTENANCE & REBOOST
 - RENDEZVOUS NAVIGATION
 - FAULT DIAGNOSIS
- COMMUNICATION AND TRACKING AN EXECUTIVE ENHANCED BY EXPERT SYSTEMS FOR:
 - COMMUNICATION SCHEDULING
 - RENDEZVOUS TRACKING
 - DATA RATE SELECTION
 - ANTENNA POINTING
- INFORMATION AND DATA MANAGEMENT AN EXECUTIVE ENHANCED BY EXPERT SYSTEMS FOR CONTROL OF:
 - SUBSYSTEM STATUISING
 - TREND ANALYSIS
 - FAULT DIAGNOSIS
 - REDUNDANCY AND CONFIGURATION MANAGEMENT
 - DATA BASE MANAGEMENT

MATURE STATION ADVANCED A&R GOALS

- PROPELLION
 - AN INTELLIGENT CONTROLLER FOR:
 - FUEL DISTRIBUTION AND MANAGEMENT
 - LEAK DETECTOR AND EVALUATOR
- ELECTRICAL POWER
 - AN AUTONOMOUS "INTELLIGENT" CONTROLLER FOR:
 - POWER MANAGEMENT
 - FAULT DETECTION AND ISOLATION
 - MAINTENANCE SCHEDULING
- GUIDANCE, NAVIGATION, AND CONTROL
 - AN INTELLIGENT CONTROLLER FOR:
 - FULLY AUTOMATIC RENDEZVOUS AND DOCKING
 - SPACE TRAFFIC CONTROL
 - REMOTELY PILOTED VEHICLES
 - COLLISION AVOIDANCE
- COMMUNICATION AND TRACKING
 - AN INTELLIGENT SYSTEM FOR:
 - AUTOMATIC PLANNING
 - TRACKING MULTIPLE VEHICLES
 - SCHEDULING BULK DATA STORAGE FOR COMMUNICATION BLACKOUTS
 - DETECTION, IDENTIFICATION, AND CHARACTERIZATION OF GENERAL TARGETS
- INFORMATION AND DATA MANAGEMENT
 - AN INTELLIGENT SYSTEM FOR:
 - FAULT DETECTION, ISOLATION, AND REPAIR
 - NATURAL LANGUAGE INTERFACE WITH CREW
 - A DATA BASE MANAGER FOR:
 - CAD/CAE BULK DATA STORAGE FACILITY
 - RETRIEVAL AND ROUTING TO REQUESTERS
- ENVIRONMENTAL CONTROL AND LIFE SUPPORT
 - AN INTELLIGENT CONTROLLER FOR:
 - ENSURING FAIL-SAFE/FAIL OPERATIONAL MODES
 - FAULT DETECTION AND ISOLATION
 - CHEMICAL ANALYSIS OF AIR/WATER
 - TOXIC GAS ANALYSIS

MATURE STATION ADVANCED A&R GOALS (CONCLUDED)

- HABITABILITY
 - AN INTELLIGENT SYSTEM FOR:
 - HEALTH MAINTENANCE
 - SPEECH INTERPRETATION AND SYNTHESIS
 - PHYSIOLOGICAL MONITORING
 - AUTOMATED MEDICAL DECISIONS
 - TREND ANALYSIS
 - ROBOTS FOR:
 - INSPECTION, MAINTENANCE, REFURBISHMENT, AND REPAIR
 - FUEL AND MATERIALS TRANSFER
 - DETECTING HAZARDOUS LEAKS
 - SATELLITE RETRIEVAL AND SERVICING
- STRUCTURES AND MECHANISMS
 - ADVANCED WORKSTATION
 - INTELLIGENT ACTUATORS
 - TELEOPERATORS

AEROSPACE INDUSTRY A&R STUDIES AND SRI TECHNOLOGY ASSESSMENT

CONTRACTOR	CONTRIBUTION
BOEING AEROSPACE CO. AND BOEING COMPUTER SERVICES CO.	SPACE STATION AUTOMATION AND ROBOTICS STUDY - OPERATOR/SYSTEM INTERFACE
GENERAL ELECTRIC, SPACE SYSTEMS DIVISION	AUTOMATION REQUIREMENTS DERIVED FROM SPACE MANUFACTURING CONCEPTS
HUGHES AIRCRAFT CO.	AUTOMATION STUDY FOR SPACE STATION SUBSYSTEMS AND MISSION GROUND SUPPORT
MARTIN MARIETTA AEROSPACE	AUTONOMOUS SYSTEMS AND ASSEMBLY
TRW SPACE AND TECHNOLOGY GROUP	SPACE STATION AUTOMATION STUDY - SATELLITE SERVICING
SRI INTERNATIONAL	NASA SPACE STATION AUTOMATION: AI-BASED TECHNOLOGY REVIEW

AUTOMATION TECHNOLOGIES TRANSFERABLE TO TERRESTRIAL APPLICATIONS

- SPACE STATION DESIGN STEP TO FLEXIBLY AUTOMATED FACTORY OF THE FUTURE
 - INTEGRATED CONTROL
 - COOPERATIVE, LESS STRUCTURED ENVIRONMENT
 - DISTRIBUTED, COOPERATIVE EXPERT SYSTEMS
- INTELLIGENT ROBOTICS IN LESS STRUCTURED ENVIRONMENTS, AS IN SERVICE INDUSTRIES
- CAD PLUS DESIGN KNOWLEDGE TRANSFORMED INTO KNOWLEDGE BASE FOR EXPERT SYSTEMS
- MAN-MACHINE INTERACTION
 - MACHINE VISION
 - SPEECH RECOGNITION AND UNDERSTANDING
 - NATURAL LANGUAGE UNDERSTANDING
 - DISPLAYS
- FAULT DETECTION AND RECOVERY

INTELLIGENT ROBOT APPLICATIONS IN U.S. ECONOMY

SETTINGS	USES
FACTORIES (MANUFACTURING, LIGHT INDUSTRY)	WELDING, MACHINING, PAINTING, MOLDING, ASSEMBLY, INSPECTION, REPAIR, LOADING, PACKAGING
OFFICES AND INSTITUTIONS (HOSPITALS, SCHOOLS, PRISONS)	DISTRIBUTION (MAIL, SUPPLIES, FOOD) CLEANING (FLOORS, WINDOWS, TRASH)
UNDERSEA	SURVEYING, SEARCH AND RESCUE, CABLE LAYING, CONSTRUCTION, EXTRACTION
MINING; OIL AND GAS	EXTRACTING, DRILLING, RESCUE (FIREFIGHTING, BORING) PROCESSING
NUCLEAR POWER PLANTS	MAINTENANCE, EMERGENCY OPERATIONS
AGRICULTURE	HARVESTING, PLANTING, IRRIGATING, FERTILIZING, WEED & PEST CONTROL
CONSTRUCTION	EXCAVATIONS, STRUCTURE ERECTION & DEMOLITION
HOME	AIDING ELDERLY OR HANDICAPPED

BENEFITS TO THE U.S.

FROM NASA ADVANCES IN AUTOMATION AND ROBOTICS

INCREASED PRODUCTIVITY IN SPACE

- NEW KNOWLEDGE
- COMMERCIAL APPLICATIONS

INCREASED PRODUCTIVITY THROUGHOUT U.S. ECONOMY

- SERVICE
- MANUFACTURING

PRESERVATION OF U.S. LEADERSHIP

- IN SPACE
- AT CUTTING EDGE OF TECHNOLOGY IN GENERAL

VOLUME II - TECHNICAL REPORT CONTENTS

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TECHNICAL REPORT CONTENTS (CONTINUED)

CHAPTER 4 - SPACE STATION SYSTEM DESIGN CONSIDERATIONS FOR ADVANCED AUTOMATION

- GENERAL DESIGN CONSIDERATIONS
- CONSIDERATIONS FOR SPACE STATION SUBSYSTEMS
- CONSIDERATIONS FOR SPACE STATION PLATFORMS
- CONSIDERATIONS FOR SPACE STATION OPERATIONS
- CONSIDERATIONS FOR SPACE STATION PAYLOADS AND EXPERIMENTS

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- MR. JOHN H. BOECKEL, DIRECTOR OF ENGINEERING, GSFC
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- MRS. DONNA L. PIVIROTTO, MANAGER OF SPACE STATION OFFICE, JPL

CAL SPACE AUTOMATION AND ROBOTICS PANEL

- PROF. J. R. ARNOLD, CAL SPACE DR. P. B. LINHART, AT&T BELL LABS
PROF. R. CANNON, STANFORD UNIV. PROF. M. MINSKY, MIT & TM
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DR. M. KNASEL, SAIC PROF. T. WILLIAMS, PURDUE UNIV.
PROF. G. KONECCI, UNIV. OF TX DR. M. WISKERCHEN, STANFORD UNIV.
PROF. G. KOZMETSKI, UNIV. OF TX

DMS DESIGN CONSIDERATIONS FOR SUPPORT OF ROBOTICS

JIMMY R. GILBERT

ARTIFICIAL INTELLIGENCE AND INFORMATION SCIENCES OFFICE
RESEARCH AND ENGINEERING DIRECTORATE

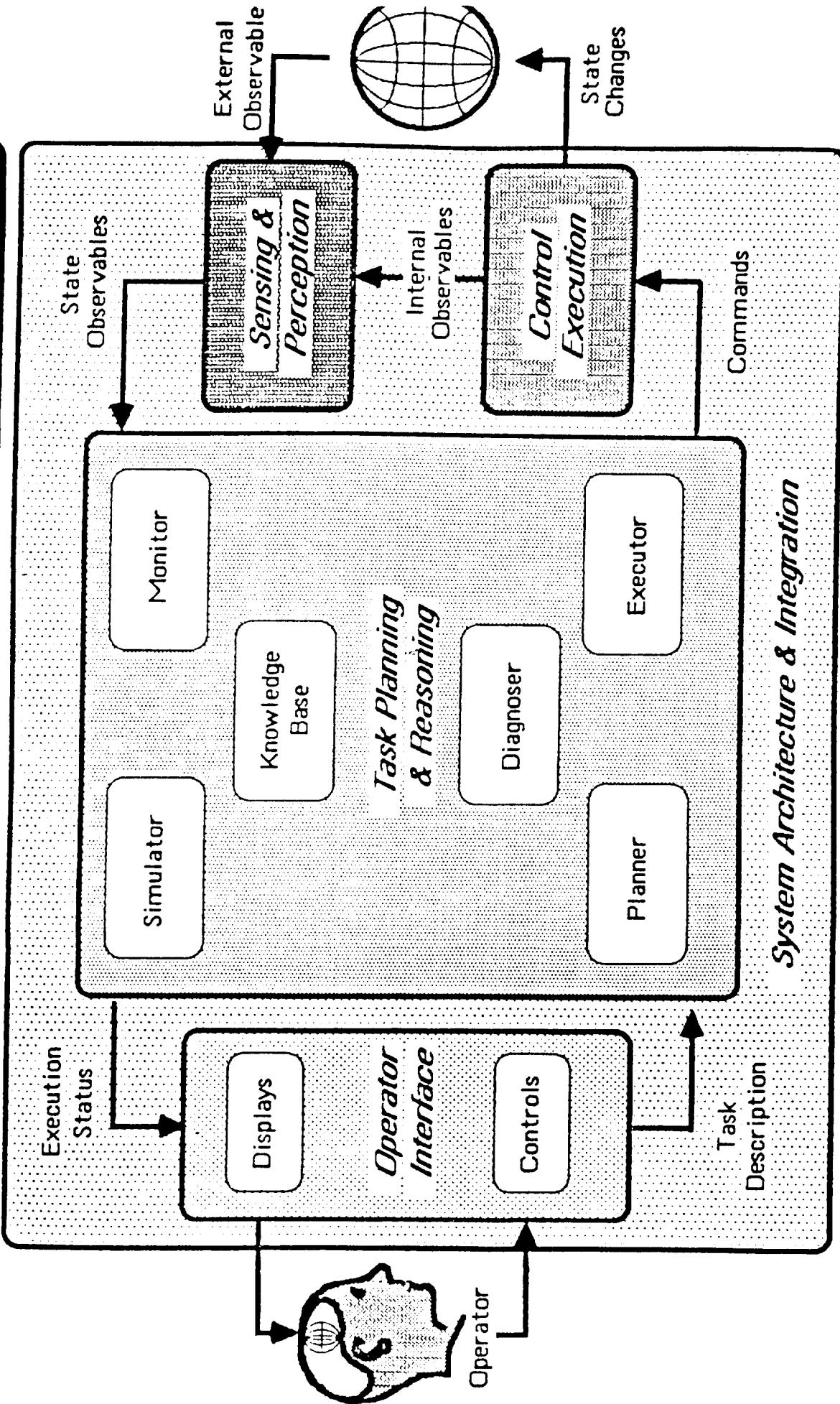
NASA JSC

SCOPE:

- o CONTROL AND DATA SUPPORT FOR
 - MOBILE REMOTE MANIPULATOR SYSTEM
 - MOBILE ASTRONAUT APPRENTICE ROBOTS
 - "GO-FER"
 - : INSPECTION
 - : ORU REPLACEMENT
 - : USER EXPERIMENT SERVICING/MAINTENANCE
 - COMMERCIAL APPLICATION ROBOTS
 - : LABORATORY SERVICING/MAINTENANCE
 - : CO-ORBITING PLATFORMS
 - OMV "SMART" FRONT END
- o TELEOPERATION, TELEPRESENCE AND SENSORY DATA
- o LOCATION AND WORLD MODEL DATA
 - INVENTORY
 - CAD/CAM/CAE
 - FAULT DIAGNOSIS
 - TREND DATA
- o WORKSTATION

Architecture for an Automated System

System Architecture & Integration



AUTOMATION AND ROBOTICS REQUIREMENTS IMPACTING DMS DESIGN

O MRRMS

- COORDINATION OF CONCURRENT OPERATIONS WITH THE SHUTTLE RMS
- ADVANCED COLLISION AVOIDANCE
- COMMUNICATION AND CONTROL ROUTING
- ACCOMMODATION OF ADVANCED SENSORS AND SMART END EFFECTORS

AUTOMATION AND ROBOTICS REQUIREMENTS IMPACTING DMS DESIGN (CONT'D)

o MOBILE ASTRONAUT APPRENTICE ROBOTS AND COMMERCIAL APPLICATIONS ROBOTS

- DMS CONSIDERATIONS FOR SUPPORTING A ROBOTIC "GO-FER" TASK PERFORMER
 - : KNOWLEDGE OF THE LOCATION OF ALL ROBOTS
 - : TELEOPERATIONS/TELEPRESENCE COMMAND AND CONTROL
 - DMS CONSIDERATIONS FOR SUPPORTING A ROBOTIC INSPECTION, MAINTENANCE, REFURBISHMENT AND REPAIR CAPABILITY
 - : ACCESS TO DMS CAD/CAM/CAE DATA BASE(S)
 - : ADVANCED SENSOR SUPPORT
 - : ACCESS TO FAULT DIAGNOSIS FUNCTIONS
 - : ACCESS TO SUBSYSTEM TREND DATA
 - ROBOT ACTIVITY PLANNING/SCHEDULING
 - COLLISION AVOIDANCE
 - COMMUNICATIONS AND CONTROL
 - CLOSE PROXIMITY MANEUVERING
- ### o OMV "SMART" FRONT END
- ACTIVITY PLANNING/SCHEDULING
 - COLLISION AVOIDANCE
 - COMMUNICATION AND CONTROL
 - CLOSE PROXIMITY MANEUVERING

- DMS GROWTH "HOOKS" AND "SCARS" AT IOC FOR INTELLIGENCE
 - o RESERVE BANDWIDTH
 - o ELECTRONIC INTERFACES WHICH ARE ROBUST (FLEXIBILITY TO INCORPORATE NEW HARDWARE)
 - o ONBOARD ACCESS TO CAD/CAM/CAE DATA BASES
 - o CAPABILITY TO SUPPORT DIVERSE SENSORS



ADVANCED TÉLÉOPERATOR TECHNOLOGY PROGRAM AT JPL

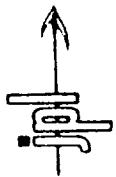
- AN OVERVIEW -

ANTAL K. BEJCZY
TECHNICAL MANAGER
AUTOMATED SYSTEMS SECTION
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

This presentation addressed the program at the Jet Propulsion Laboratory for the development of sensors (tactile, proximity, torque) and graphics for teleoperation. In tactile sensing, JPL developed a small pad containing a matrix of 32 sensors that fits on a robot gripper. The sensors are connected to processor using a fiber optic linkage. They have also developed a proximity detector-ranging device that fits on the end of the gripper and that automatically positions the gripper within a fixed distance from a surface. This proximity detector will allow an operator to move a robot arm along paths that remain a fixed distance from the work surface. Another type of gripper that has been developed at JPL is a torque-sensing gripper. This device consists of three or four fingers mounted on a sensing ring. When a force is applied to the end of a finger the resulting torque is measured at the ring.

To display the measurements from the various sensors being studied, JPL has developed a series of graphic displays. One of the displays shows the forces (or torques) as horizontal bars. Another is a pseudo-three-dimensional display that lets the operator see up, down, right, left, forward, and backward forces on the gripper.

NASA INTERCENTER A&R INFORMATION MEETING
JOHNSON SPACE CENTER
HOUSTON, TEXAS
MAY 17, 1985



CONTENT

- o SCOPE OF WORK
 - o HISTORY
 - o ILLUSTRATIVE R&D ACCOMPLISHMENTS
 - o ONGOING WORK
 - o FUTURE PLANS
-
-

APPENDIX: LIST OF PUBLICATIONS



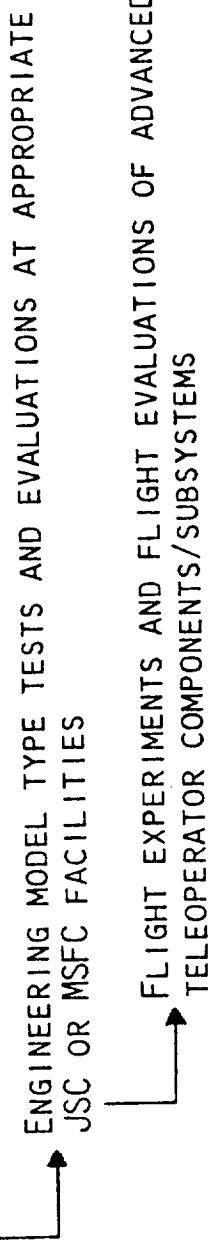
SCOPE OF WORK

o TECHNICAL GOALS AND AREAS

- o TASK ANALYSIS AND REQUIREMENTS DEVELOPMENT
- o INTELLIGENT SENSING (NON-VISUAL & VISUAL)
- o SMART END EFFECTORS
- o INTELLIGENT MAN-MACHINE INTERFACE
 - o INTELLIGENT CONTROLS (MANUAL, COMPUTER, VOICE)
 - o INTELLIGENT DISPLAYS (AUDIO AND GRAPHICS)
- o CONTROL STATION ARCHITECTURES
- o HUMAN FACTORS DATA BASE DEVELOPMENT

o TECHNICAL APPROACH

IN-HOUSE BENCH-MODEL TYPE FEASIBILITY DEMOS





HISTORY

O PROJECTS

- 1971-80: REMOTELY MANNED SYSTEMS R&D; ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT (OSS - LIFE SCIENCES)
- 1978-85: SPACE SHUTTLE RMS AND OMV MANIPULATOR SENSOR/CONTROL ENHANCEMENT (CODE M & JSC DDF)
- 1982-85: TELEOPERATOR HUMAN INTERFACE TECHNOLOGY; INTERACTIVE AUTOMATION (CODE RTI & RTC)
 - 1979-82: SMART HAND - SENSORY FEEDBACK CONTROL (NSF - UNIV. OF ARIZONA)
 - 1980-83: ADVANCED SERVOMANIPULATOR M/M INTERFACE CONCEPTUAL DESIGN; DUAL ARM MASTER CONTROLLER & HAND GRIP DEVELOPMENT (ORNL - DOE)
 - 1982-85: INDUSTRIAL ROBOT APPLICATION OF IR RANGE SENSING (NASA - TU)

O GROUND DEMOS OF ENGINEERING MODELS AT JSC MDF FOR RMS CONTROL ENHANCEMENT

- 1978: PROXIMITY SENSORS - SIMPLE DISPLAY
- 1980: PROXIMITY SENSORS - ADVANCED DISPLAY
- 1981: VOICE CONTROL OF TV CAMERAS/MONITORS
- 1982: FORCE-TORQUE SENSOR/DISPLAY & FOUR-CLAW END EFFECTOR, |
1984: FORCE-TORQUE SENSOR/DISPLAY & FOUR-CLAW END EFFECTOR, | |.

JPL →

ILLUSTRATIVE R&D ACCOMPLISHMENTS

- SENSORS (PROXIMITY, TACTILE, SLIP, FORCE-TORQUE)
- SMART HANDS
- GRAPHIC DISPLAYS
- VISUAL SYSTEMS (MONO & STEREO)
- CONTROLS (GENERALIZED FORCE-REFLECTING MANUAL, INTERACTIVE COMPUTER, VOICE)
- HUMAN PERFORMANCE EXPERIMENTS

(PICTURES & VCR'S)

AKB, Ø5/17/85



ONGOING WORK

- o DISTRIBUTED COMPUTING FOR INTERACTIVE MANUAL/AUTOMATIC CONTROL
 - o OMV - SMART HAND DEVELOPMENT (INCLUDING GRASP FORCE SENSING)
 - o HIGH-POWER GRAPHICS DISPLAYS (3D AND PREDICTIVE)
 - o HUMAN PERFORMANCE EXPERIMENTS (VISUAL & KINESTHETIC/ZERO-G)
 - o RMS FORCE-TORQUE SENSOR FLIGHT EXPERIMENT
-
-

UNIVERSITY CONTRACTS

- o USC
- o UCB
- o MIT

6

AKB, 05/17/85

JPL →

FUTURE PLANS

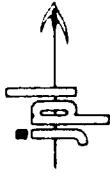
- o BROADENING SCOPE OF WORK ACCORDING TO "TELEBOTICS NEW INITIATIVE" PLANS
 - o MULTIPLE ARMS & MULTIPLE OPERATORS
 - o TASK-LEVEL CONTROLS/DISPLAYS
 - o INTENSIFIED ON-LINE & OFF-LINE COMPUTER AIDS
 - o INTELLIGENT INTERFACE TO INTELLIGENT SYSTEMS/SUBSYSTEMS
- o BROADENING HUMAN PERFORMANCE EXPERIMENTS
 - o VISUAL/GRAFIC SYSTEMS
 - o ANALOG CONTROLS
 - o SYMBOLIC CONTROLS ("COMMAND/CONTROL LANGUAGE")
- o BROADENING FLIGHT EXPERIMENTS PREPARATION



APPENDIX

JPL ADVANCED TELEOPERATOR TECHNOLOGY DEVELOPMENT

PUBLICATIONS



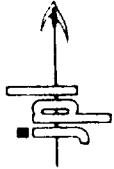
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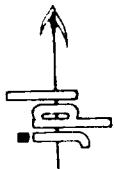
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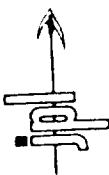
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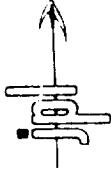


MACHINE VISION RESEARCH AT JPL

BRIAN WILCOX

ROBOTICS AND TELEOPERATORS RESEARCH GROUP
AUTOMATED SYSTEMS SECTION

This presentation addresses the development at JPL of a computer vision approach for recognizing shapes that are made up of convex polyhedra. The approach finds first the edges in the image and then, using this edge data, locates vertices. Assuming that the image is moving, the velocity of each vertex is computed. Using a stored model of the image, this velocity data is used to match-up neighboring vertices and thereby recognize the image. This vision approach allows a robot that is moving with respect to a target to identify it and grab it. The approach is being implemented on a pipe-line computer called PIFEX (Programmable Image Feature Extractor).



GOALS OF JPL PROGRAM IN MACHINE VISION:

AUTONOMOUS ACQUISITION AND TRACKING OF LABELED OR
UNLABELED OBJECTS

VISION-BASED GUIDANCE OF AUTONOMOUS PLANETARY ROVERS

PREVIOUSLY-DEMONSTRATED ELEMENTS OF PROGRAM:

IMFEX (IMAGE FEATURE EXTRACTOR)

ROBUST REAL-TIME TRACKING OF SIMPLE UNLABELED OBJECTS

TRACKING AND GRAPPLING OF LABELED OBJECT

CURRENT WORK:

PIFEX (PROGRAMMABLE IMAGE FEATURE EXTRACTOR)

AUTONOMOUS ACQUISITION OF POSITION/ORIENTATION OF
UNLABELED CONVEX POLYHEDRA

INTERACTIVE PATH DESIGNATION FOR PLANETARY ROVERS

PLANNED WORK:

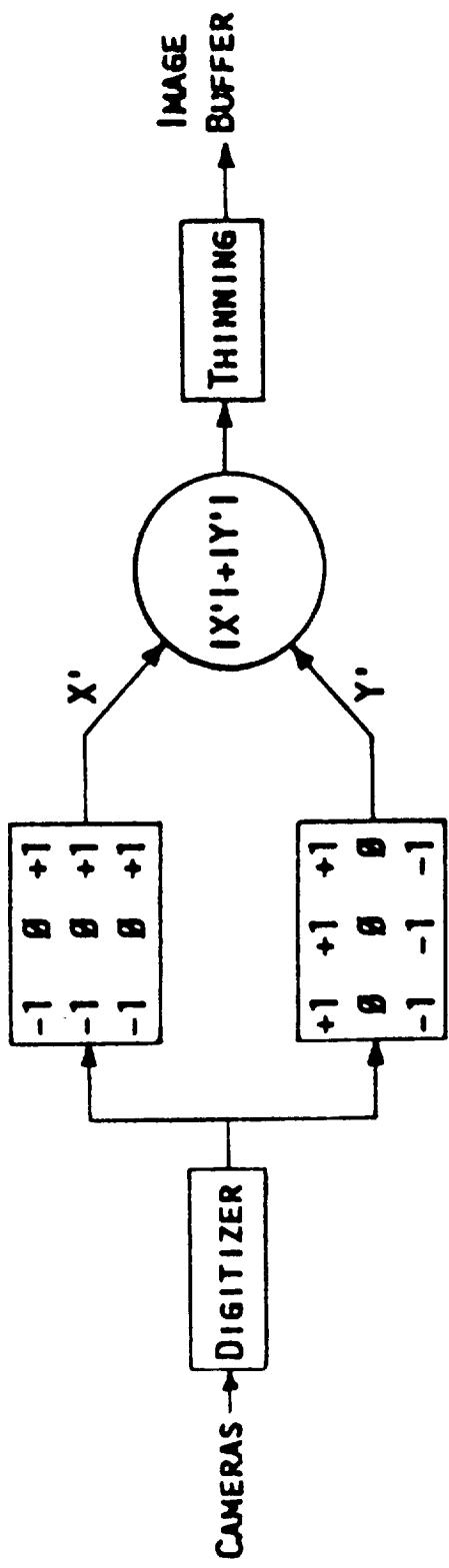
ACQUISITION AND TRACKING OF NONCONVEX/CURVED/COMPLEX OBJECTS

INTERACTIVE/AUTONOMOUS OBJECT MODEL CREATION

SEMI-AUTONOMOUS PATH PLANNING FOR ROVERS

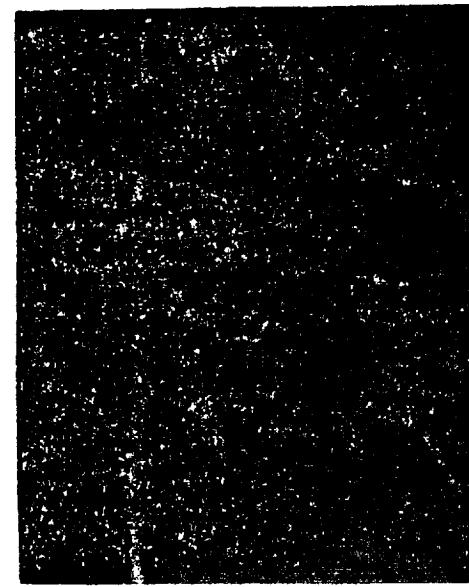
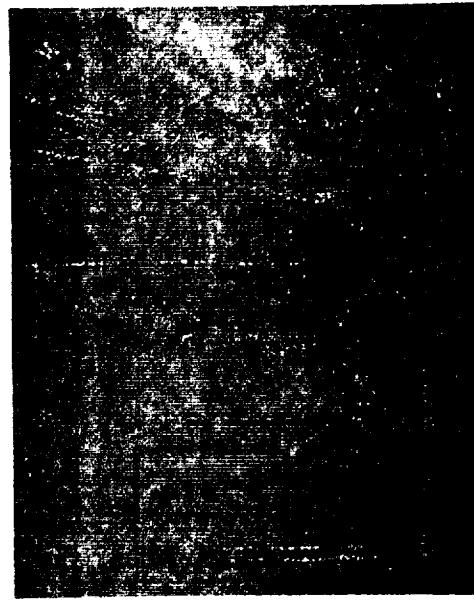
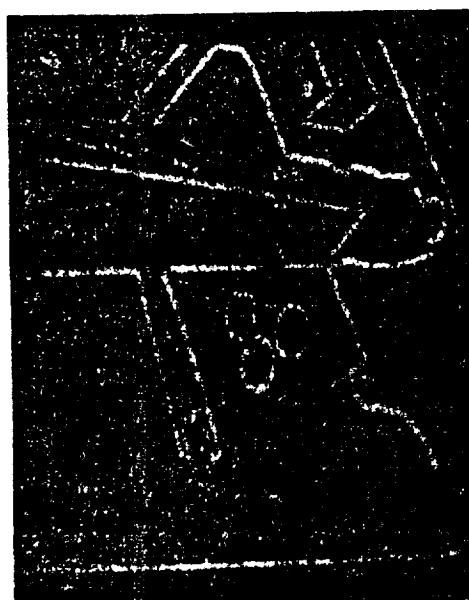
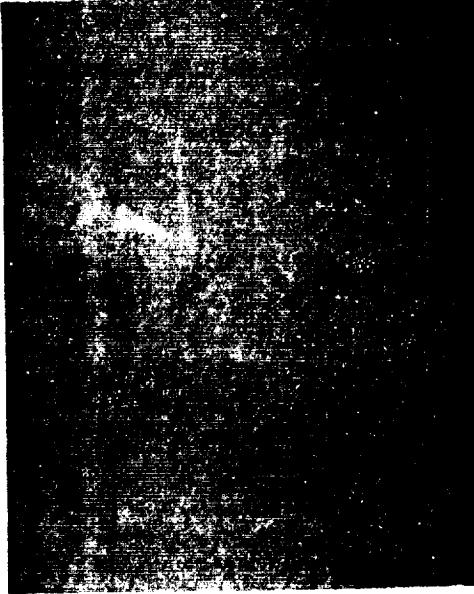
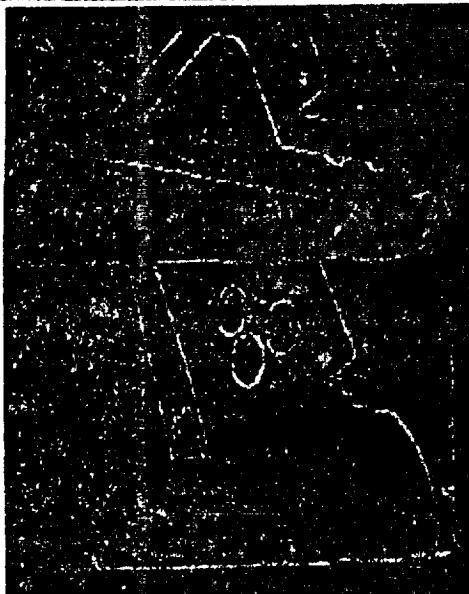


CURRENT IMEX ARCHITECTURE:

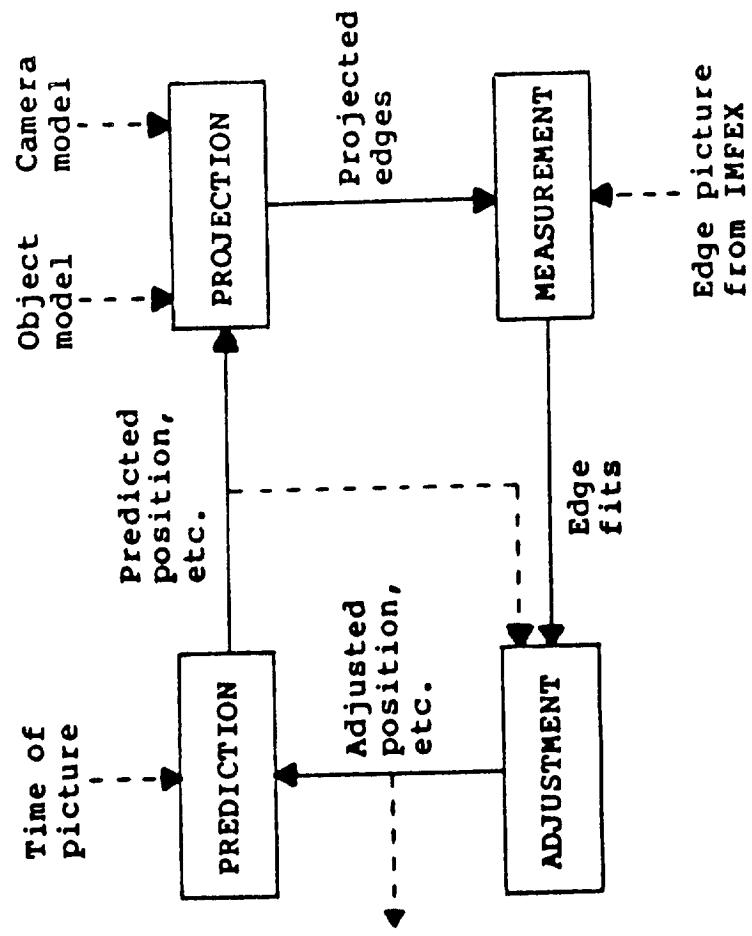


FEATURES:

- REAL-TIME EDGE DETECTION AND THINNING
- STATE-OF-THE-ART IN 1978

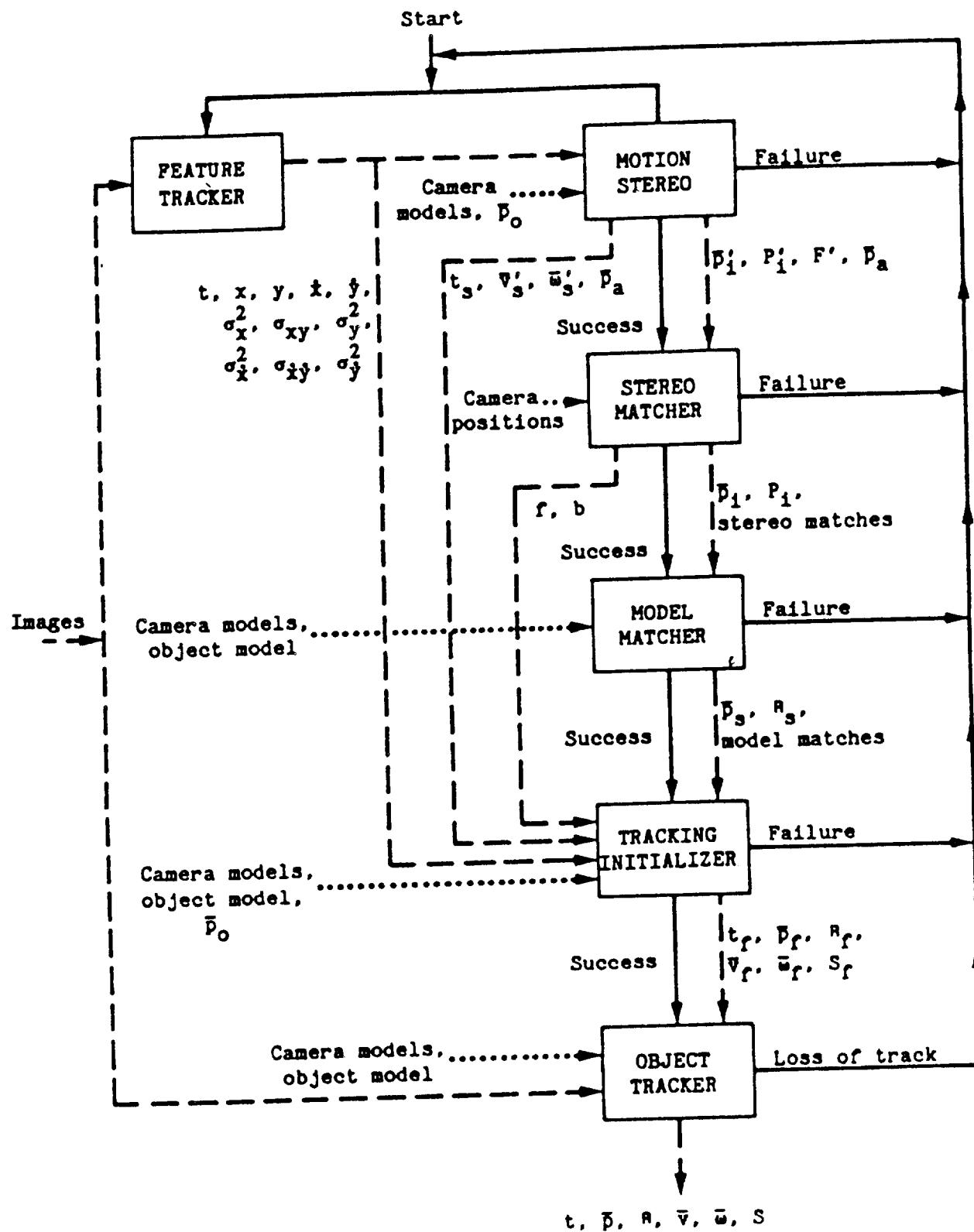


3-D TRACKER FLOW CHART



ACQUISITION

- ACQUIRES MOVING OBJECT FOR WHICH AN OBJECT MODEL IS AVAILABLE, FOR TRACKING WITH SIX DEGREES OF FREEDOM.
- USEFUL FOR RETRIEVAL OF SATELLITES.
- USEFUL FOR HANDLING WORK PIECES, REPLACEMENT MODULES, AND FASTENERS IN ORBITAL ASSEMBLY WORK.



Acquisition and tracking block diagram.

Legend for Figure

Symbols for 3-D quantities (prime means uncorrected for scale factor and bias):

\bar{p} position vector
 \bar{P} 3-by-3 covariance matrix of position
 \bar{R} orientation quaternion
 \bar{v} velocity vector
 $\bar{\omega}$ angular velocity vector
 \bar{S} 12-by-12 covariance matrix of position, orientation, velocity, and angular velocity

Subscripts on above:

i each feature (at time t_s)
s object at time t_s (\bar{v}_s refers to reference point instead of object origin)
f object at time t_f (final data used for acquisition)
o reference (a priori object)
a average feature

Symbols for 2-D quantities for each feature:

x horizontal position
y vertical position
 \dot{x} horizontal velocity
 \dot{y} vertical velocity
 σ standard deviation of quantity or covariance of quantities indicated by subscript

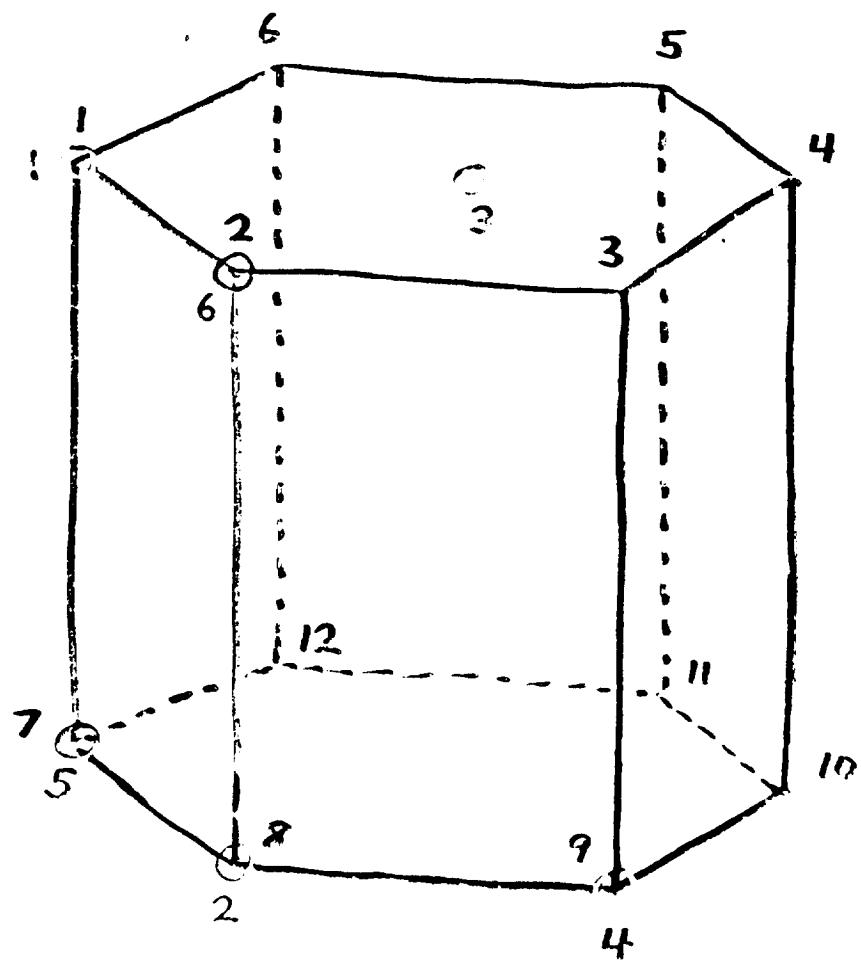
Other quantities:

t time
f scale factor
b bias
F 2-by-2 covariance matrix of scale factor and bias

Flow:

— program
— — — data derived from images
..... principal given data

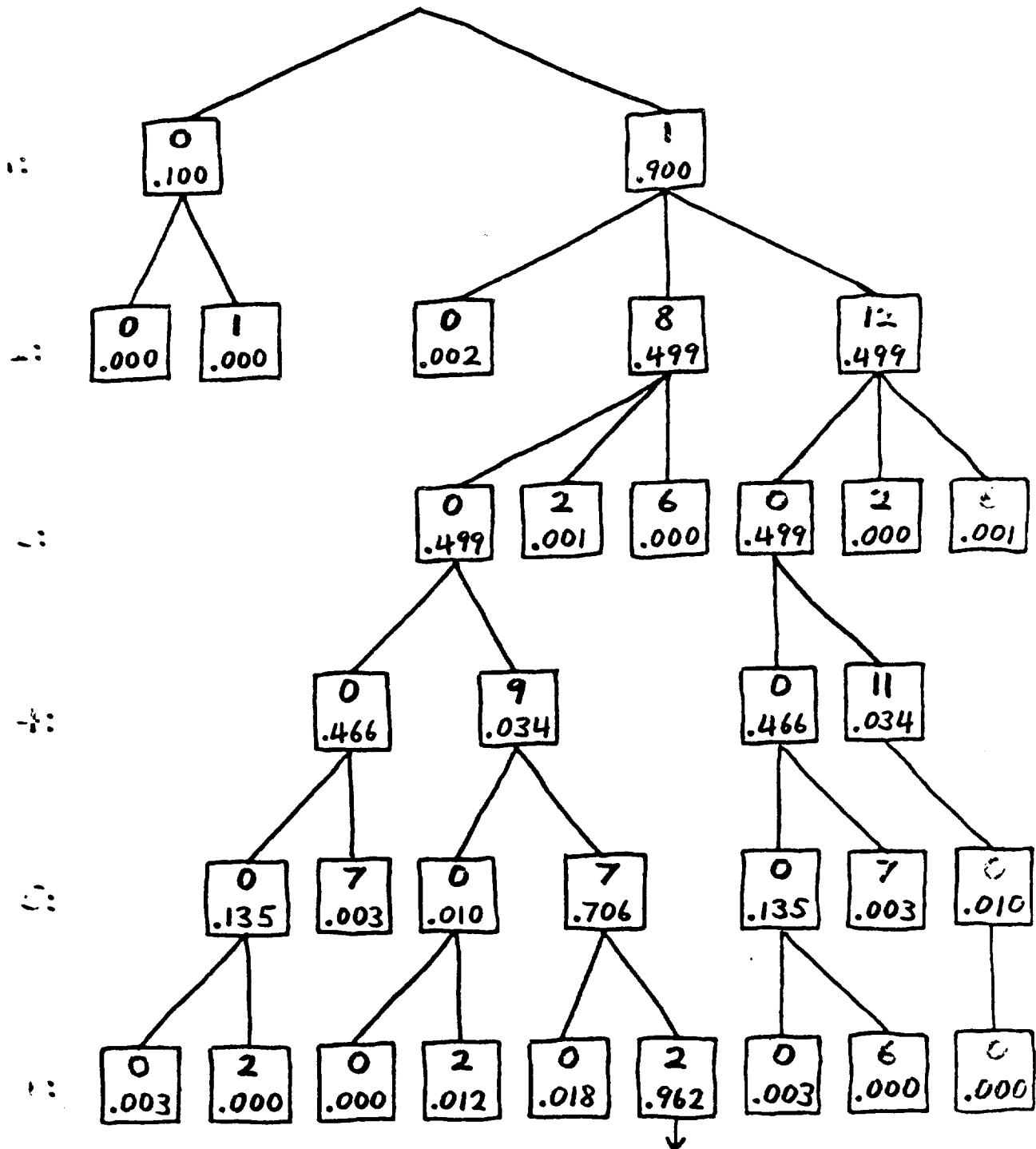
Example of object
Example of data

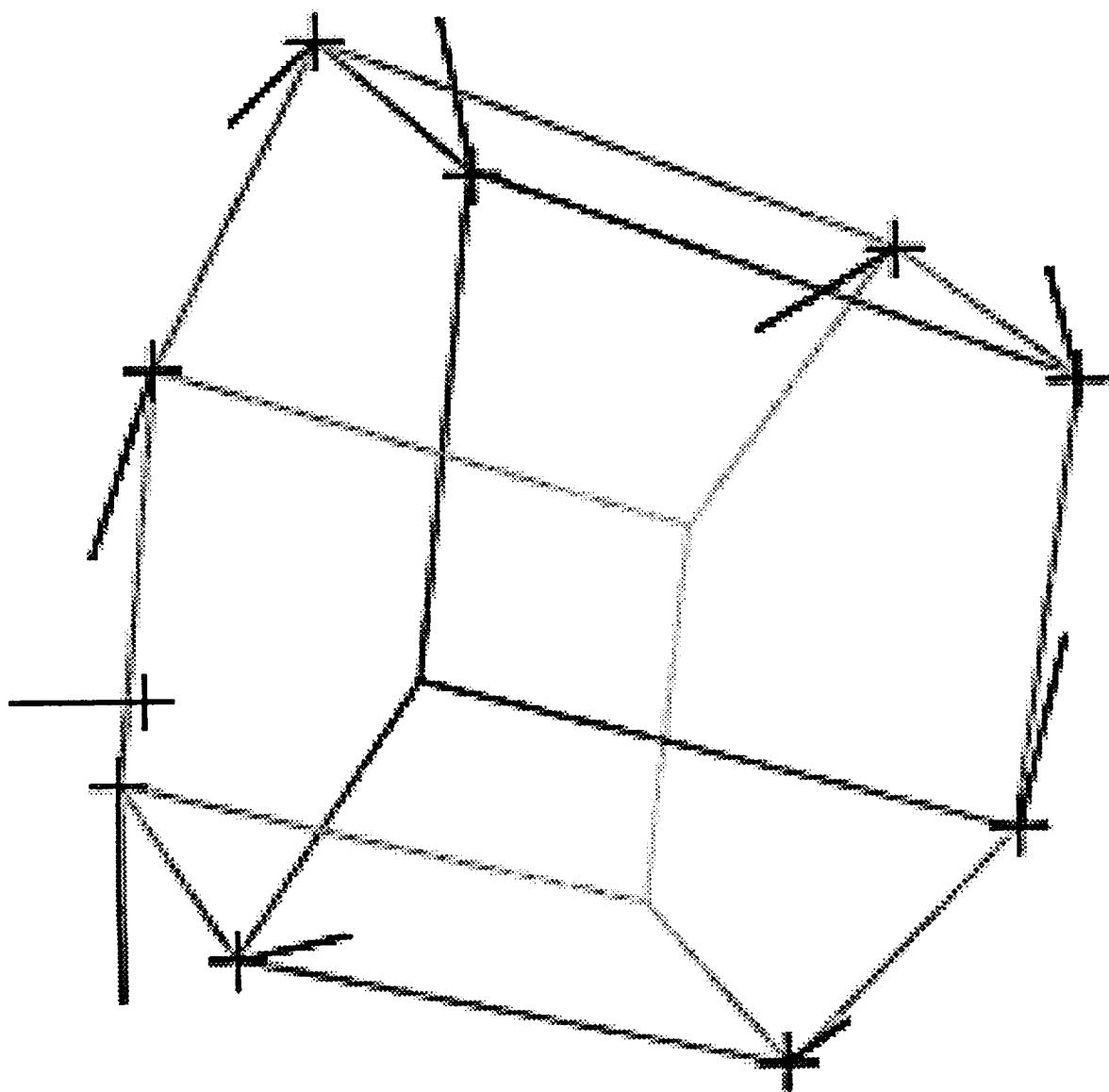


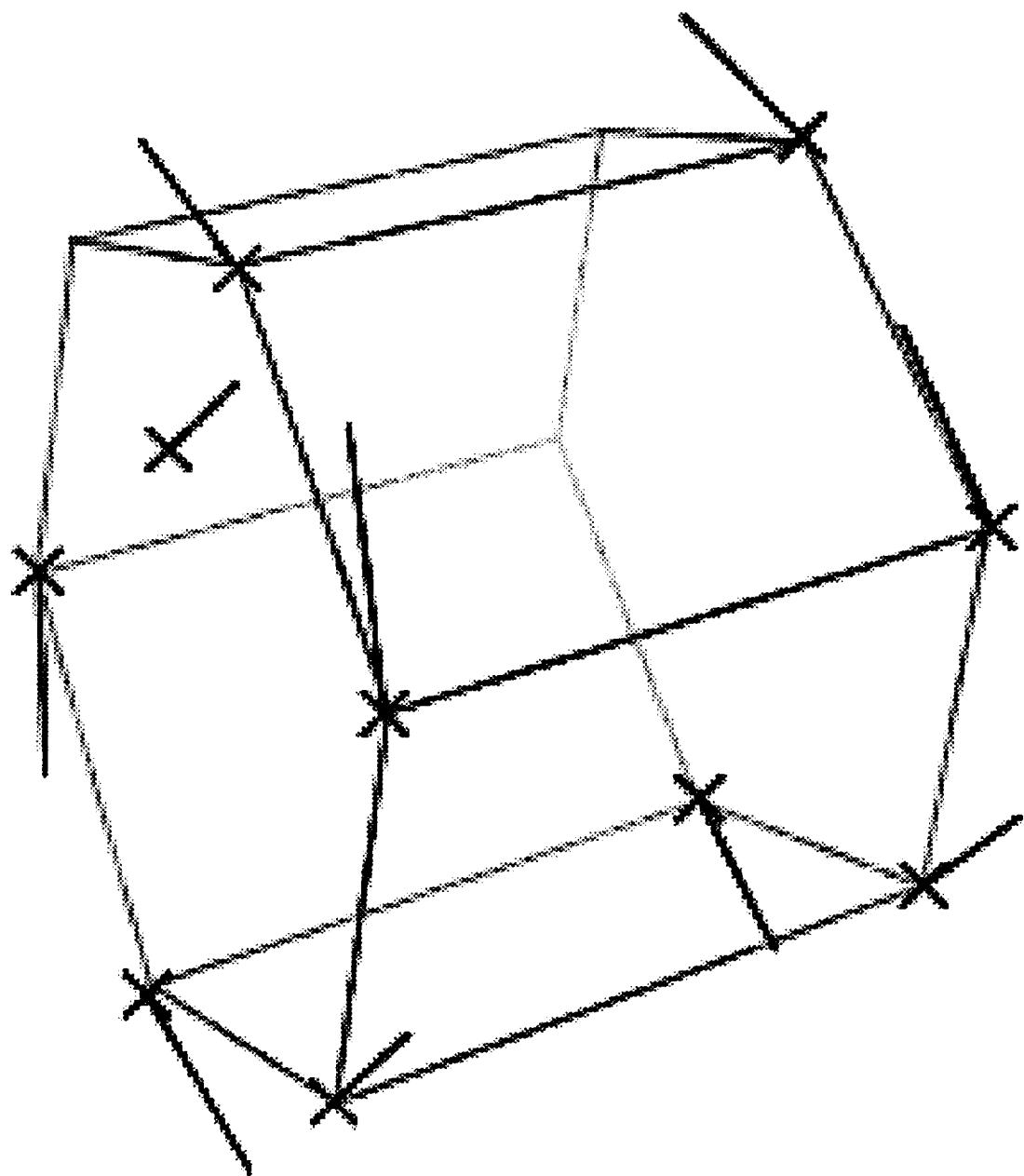
SEARCH TREE IN MODEL MATCHER FOR EXAMPLE

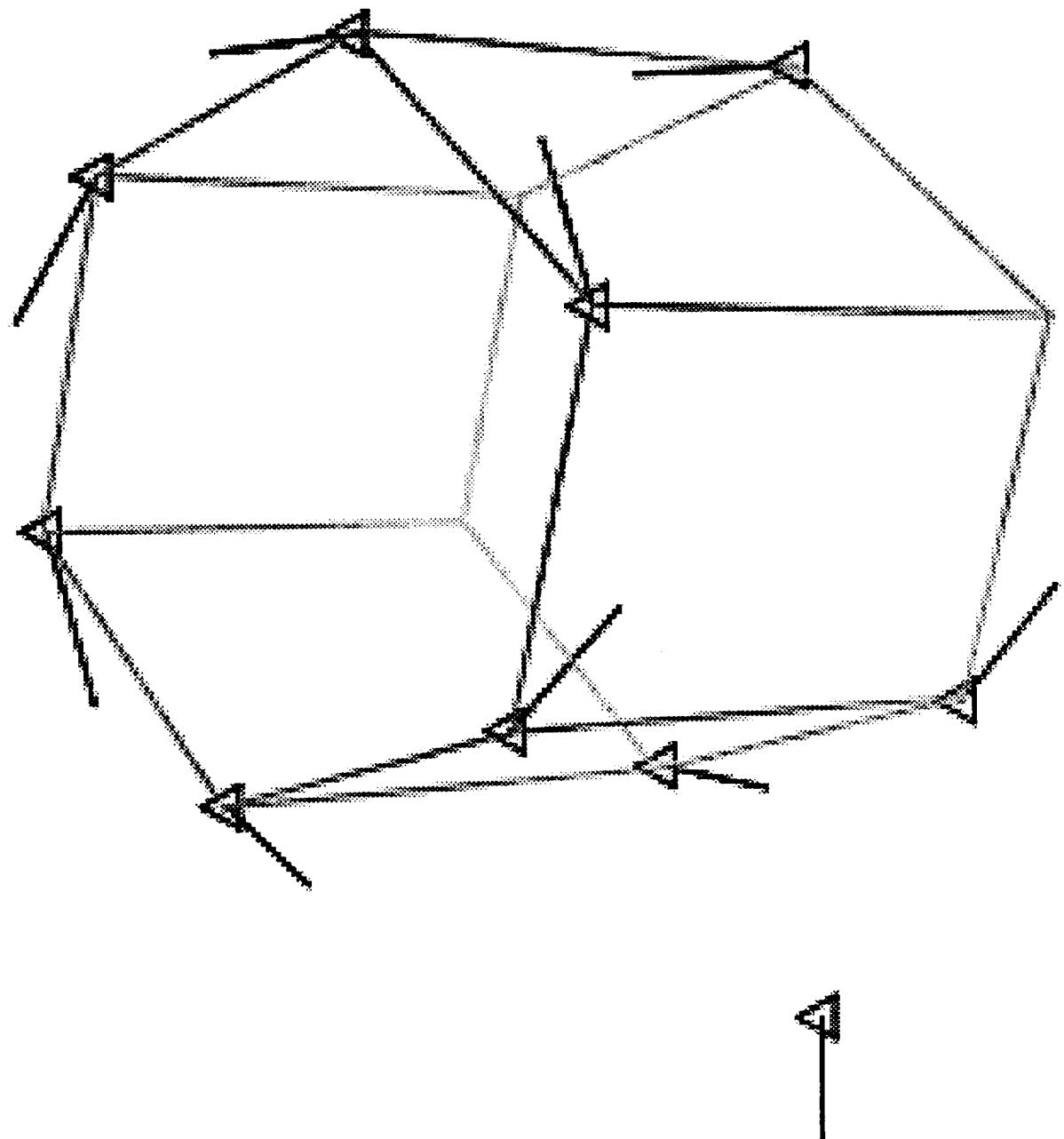
-> frustum fracture

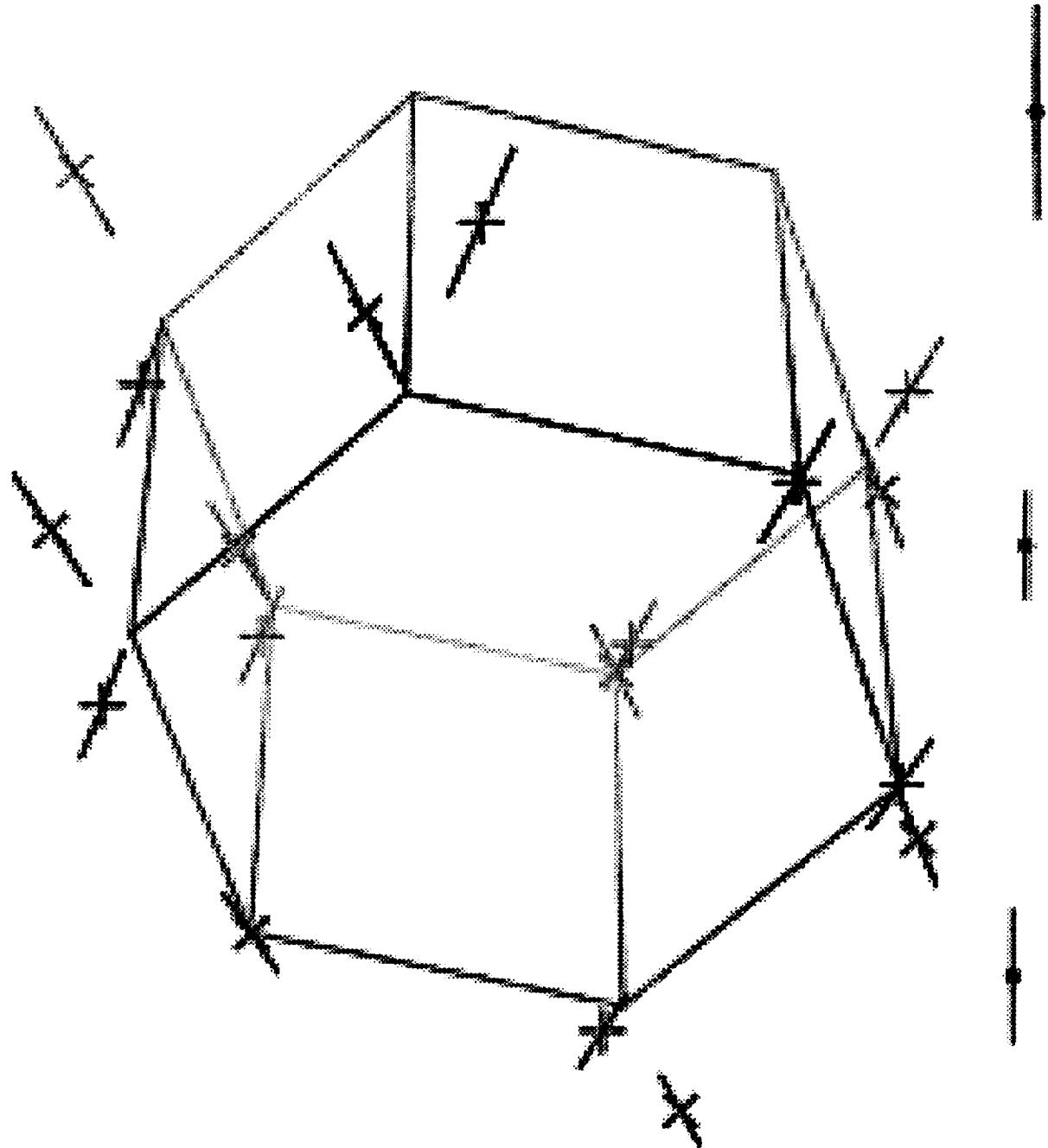
Object vertex
Probability

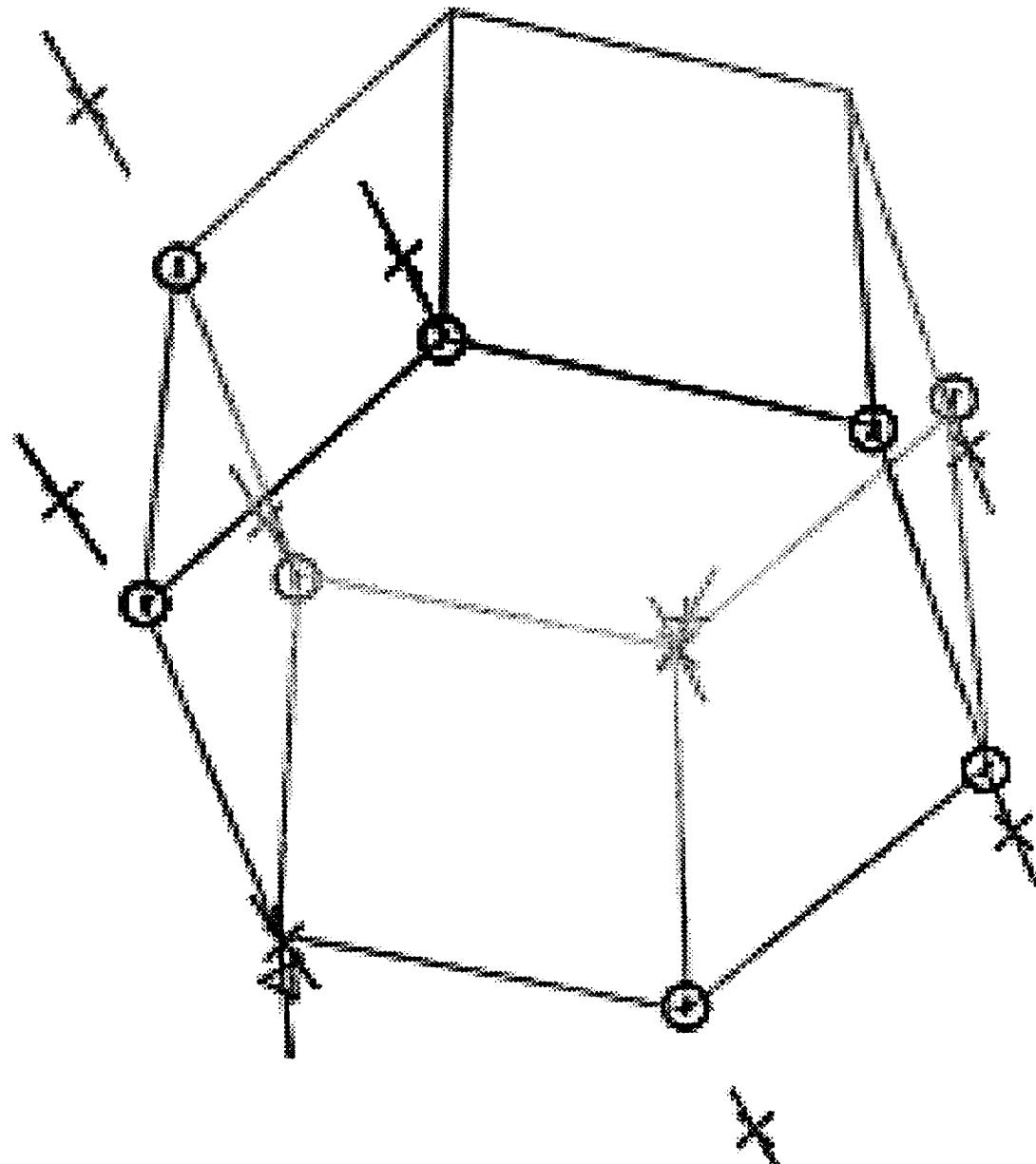












1000

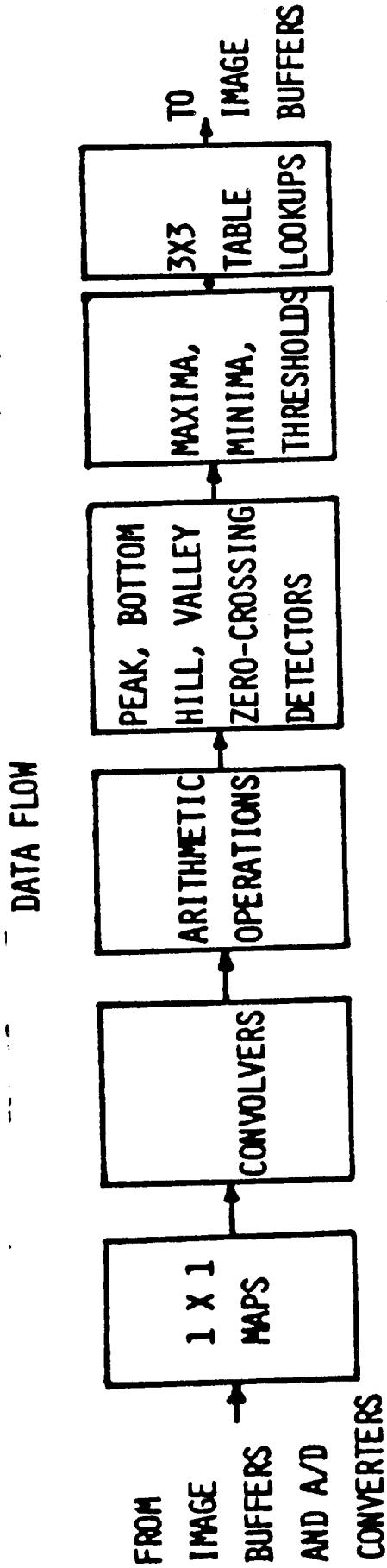
NEEDS WHICH LED TO PIFEX CONCEPT:

- EXTRACT FEATURES OTHER THAN EDGES IN REAL-TIME
- INTERFACE TO MODERN COMPUTER
- HIGHER RESOLUTION SOLID-STATE CAMERAS
- LOW-LEVEL VISION NEEDS WELL OVER 10^9 OPS/SEC
(COMPARED TO 10⁷ FOR INFEX)
- EXPANDABLE PIPELINED ARCHITECTURE APPLICABLE TO
WIDE RANGE OF NASA, INDUSTRY, AND MILITARY
VISION TASKS.



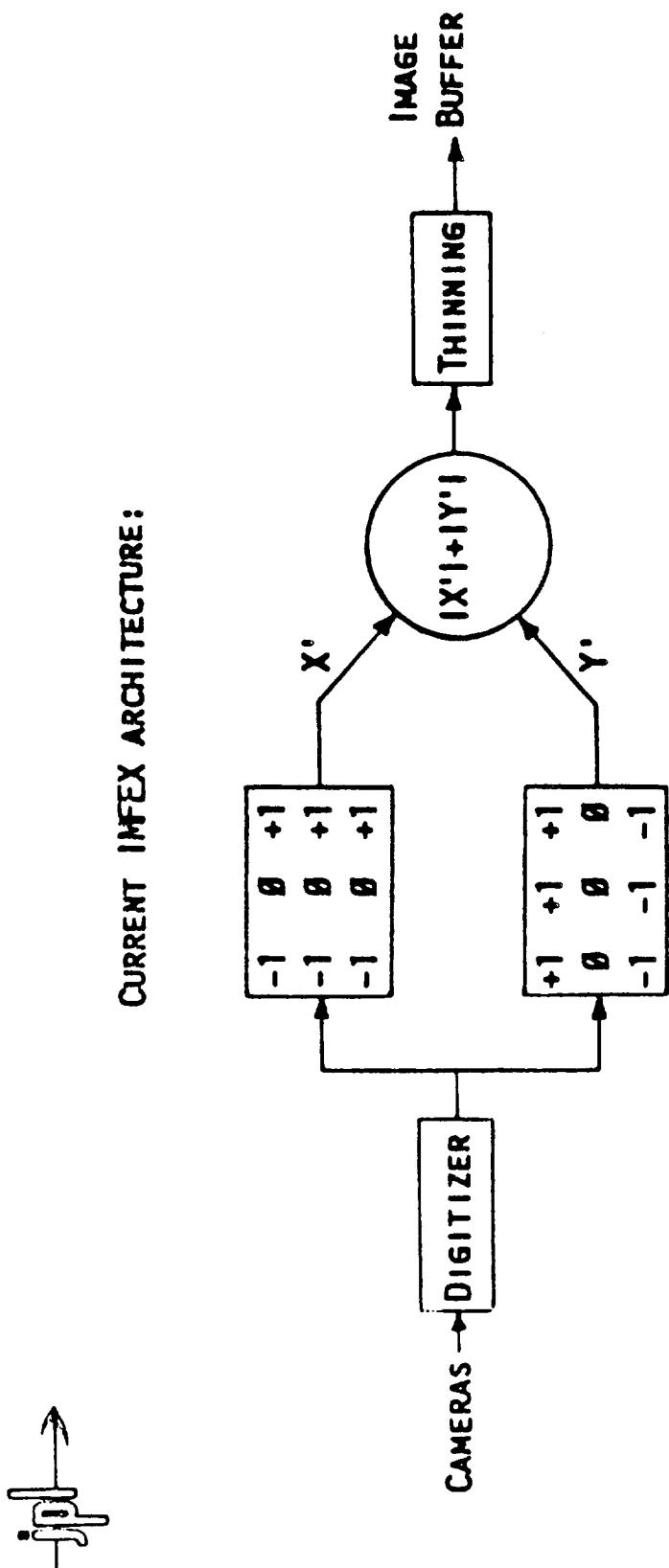
JPL →

PROGRAMMABLE IMAGE FEATURE EXTRACTOR (PIFEX)
IN CONCEPTUAL DEVELOPMENT AT JPL



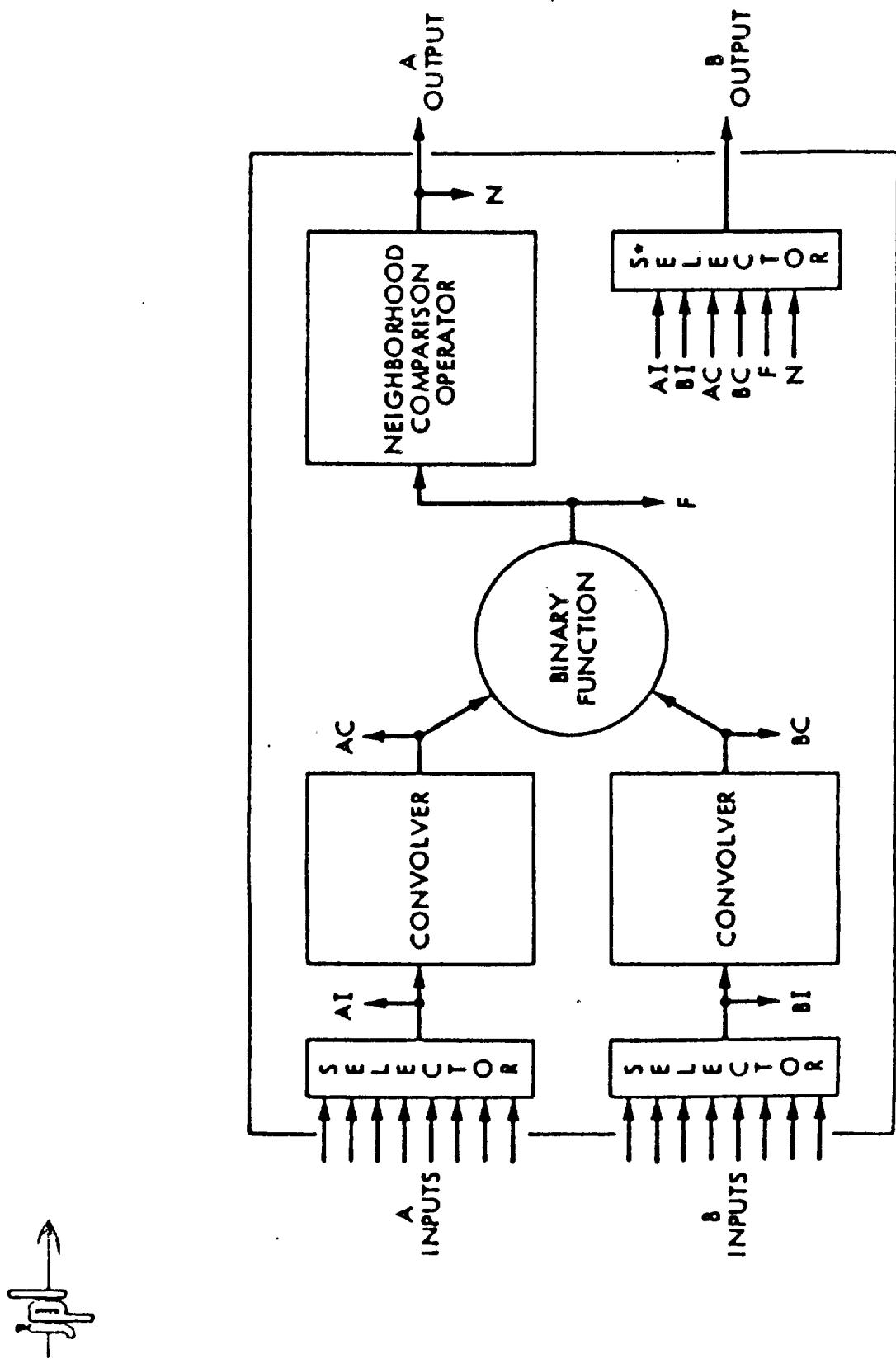
- GENERALIZED PIPE-LINE PREPROCESSOR
- PROGRAMMABLE TO USER DESIRED APPLICATION
- VLSI CHIP SET PERMITS 10² FASTER SPEED
AND MINIATURIZED PACKAGING

CURRENT IMEX ARCHITECTURE:



FEATURES:

- REAL-TIME EDGE DETECTION AND THINNING
- STATE-OF-THE-ART IN 1978



PIFEX MODULE

- INCLUDES APPROPRIATE DELAYS

-jpl →

MSI DEVELOPMENT FOR PIFEX

CHIPS DEVELOPED AT THE JPL MSI DESIGN CENTER:

- FABRICATED COURTESY OF DARPA MOSIS
- USES HEAD-COMA METHODOLOGY -- SIMPLIFIED DESIGN RULES
- WILL FABRICATE PROTOTYPES, PRODUCTION RUNS, CIRCUIT BOARDS

CONVOLVER CHIP FOR USE IN PIFEX:

- NINE ARRAYS OF ONE-BIT FULL ADDERS, 765 IN ALL
- SIX-BIT SIGNED WEIGHTS
- 17-BIT INTERNAL DATA PATH TO RETAIN PRECISION
- UNSIGNED OR TOS COMPLEMENT PIXEL DATA

CONVOLVER

$$\text{CONVOLVER COMPUTES } G_{I,J} = 2^{-N} \sum_{K=-1}^1 \sum_{L=-1}^1 W_{K,L} F_{I-K, J-L} + C.$$

INPUT F AND OUTPUT G ARE 12 BITS, UNSIGNED OR TWO'S COMPLEMENT FOR NEGATIVE.

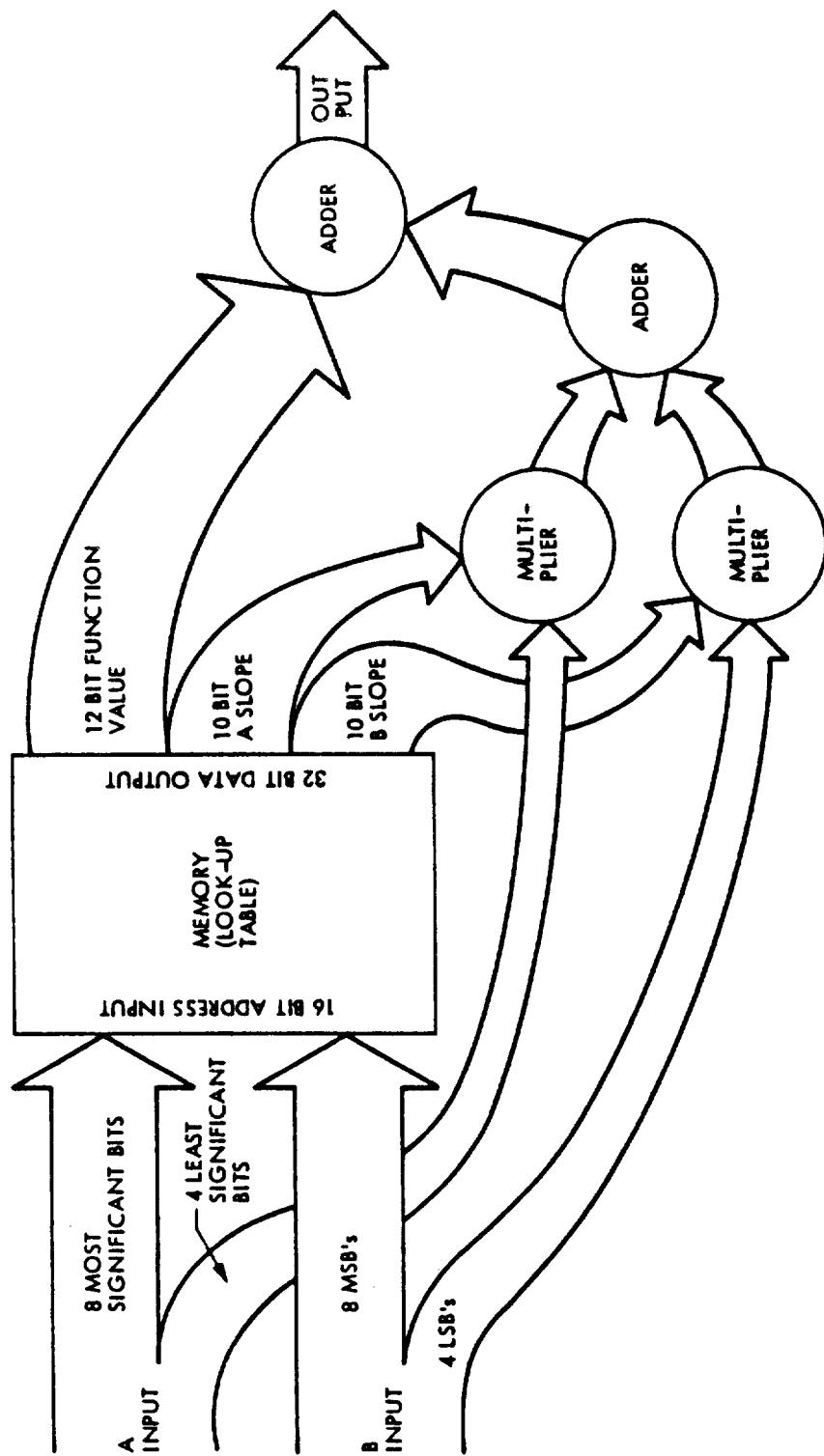
PROGRAMMABLE WEIGHTS W ARE 6 BITS INCLUDING SIGN BIT.

THE CONSTANT C IS PROGRAMMABLE.

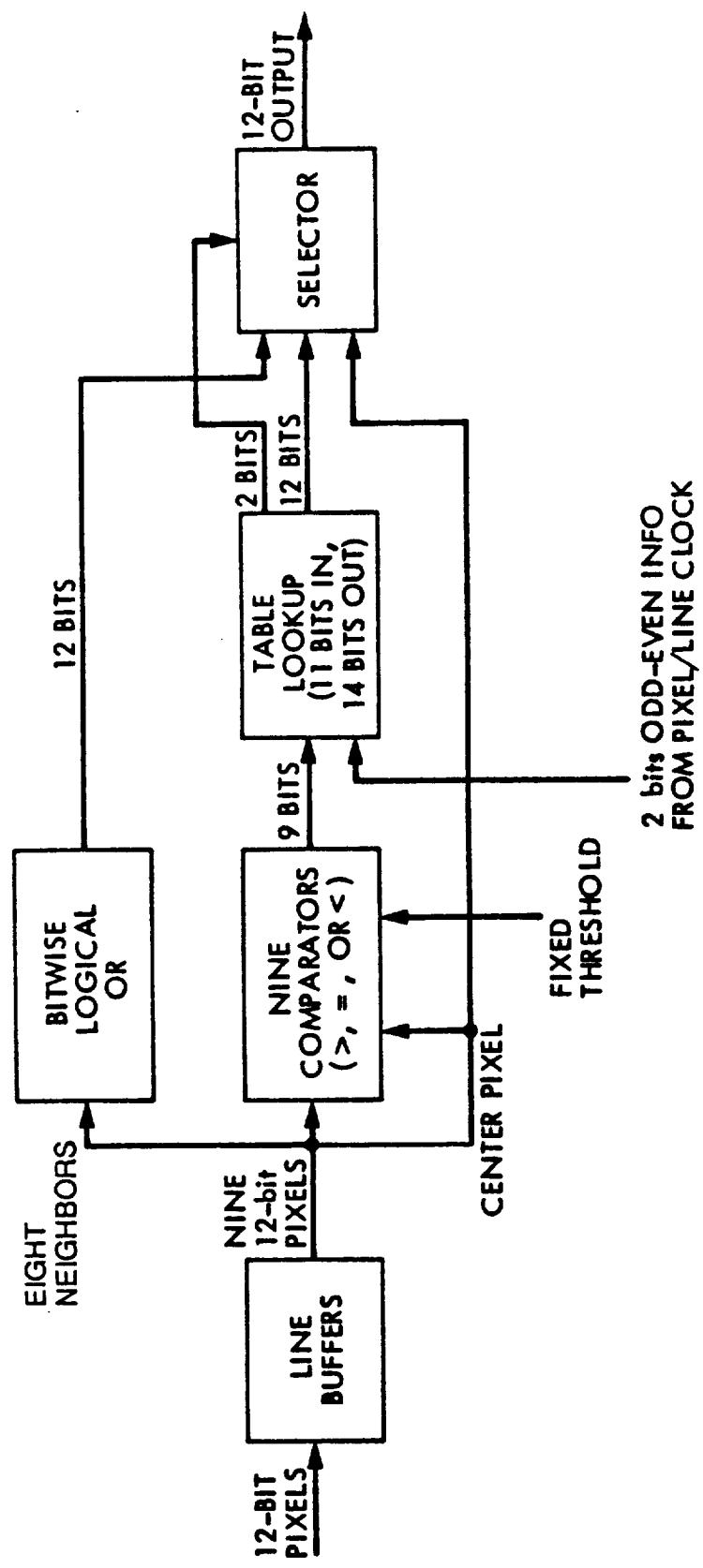
INTERNAL DATA PATH IS 17 BITS, WITH PROGRAMMABLE SHIFTS THAT DETERMINE N.

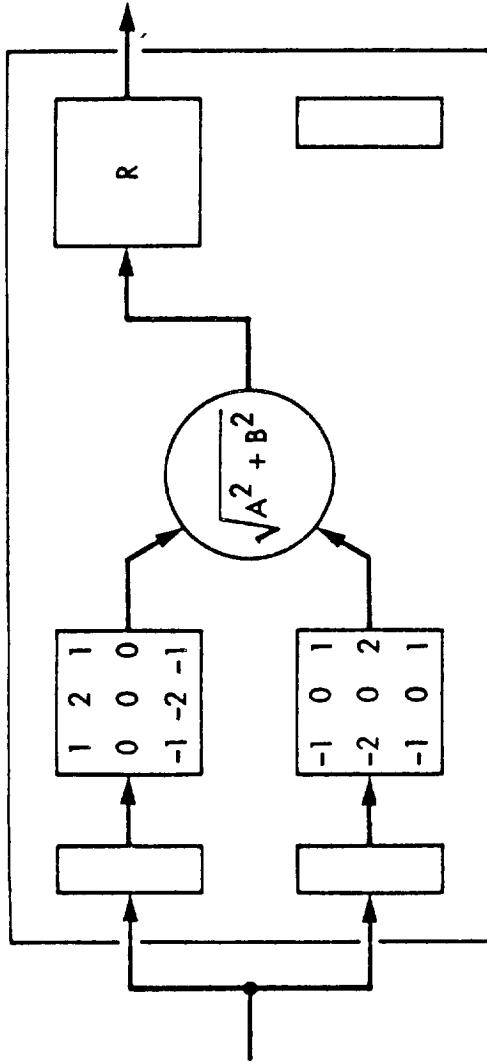
CONVOLVER CONSISTS OF ONE CUSTOM VLSI CHIP PLUS LINE BUFFERS.

BINARY FUNCTION

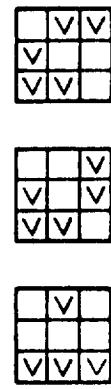


NEIGHBORHOOD COMPARISON OPERATOR





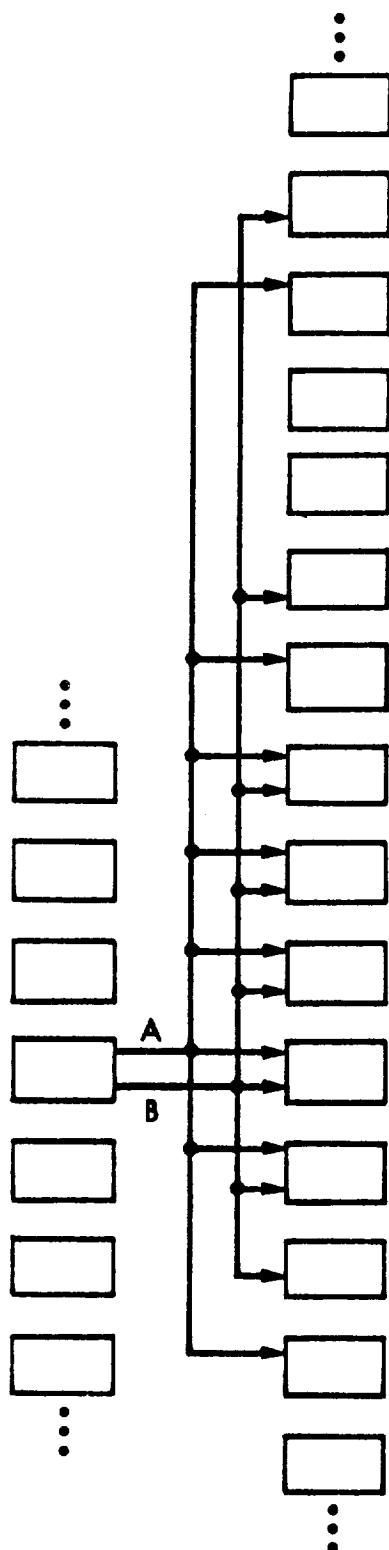
- A UPPER INPUT TO FUNCTION (OUTPUT OF A CONVOLVER)
- B LOWER INPUT TO FUNCTION (OUTPUT OF B CONVOLVER)
- R RIDGE OPERATOR: IF ANY OF THE FOLLOWING PATTERNS OR THEIR ROTATIONS EXISTS:



WHERE < MEANS "LESS THAN THE CENTER" AND BLANK MEANS "DON'T CARE,"
OUTPUT THE CENTER PIXEL; OTHERWISE, OUTPUT ZERO.

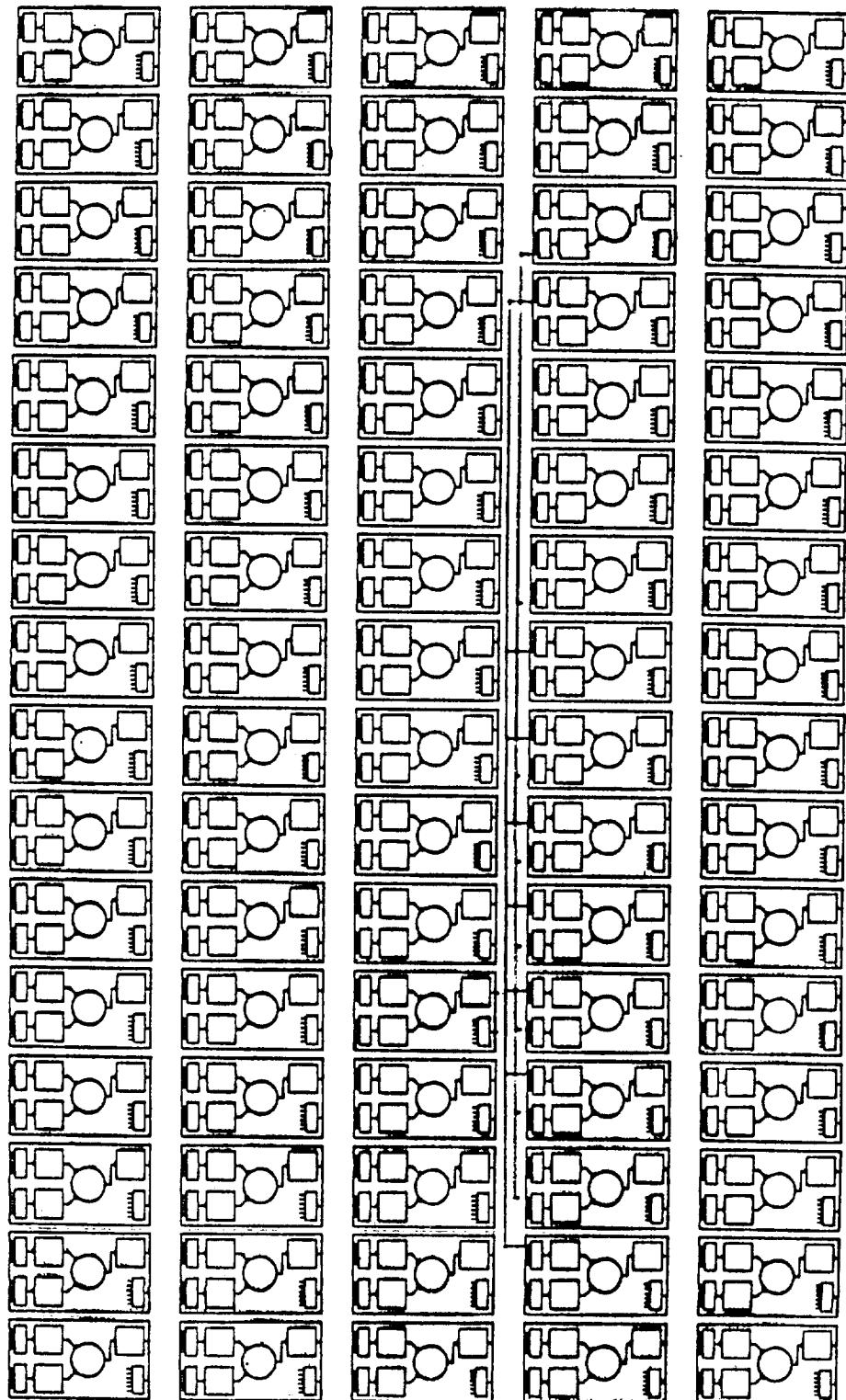
SOBEL OPERATOR WITH THINNING

INTERCONNECTION OF MODULES



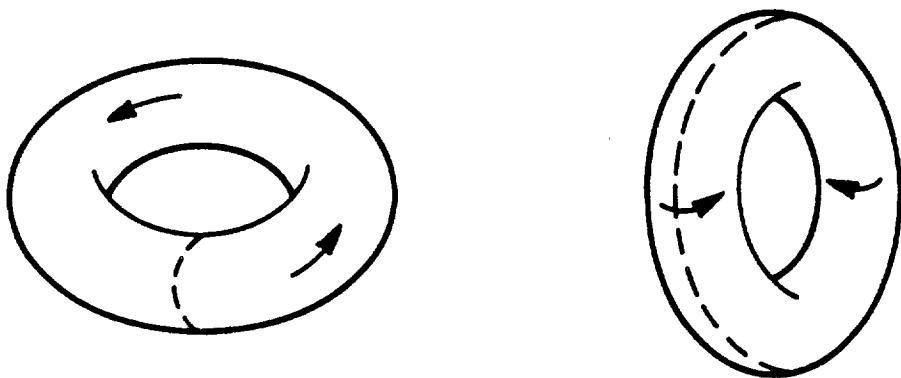
THE CONNECTIONS FROM A PARTICULAR MODULE IN ONE COLUMN
TO THE MODULES IN THE NEXT COLUMN ARE SHOWN.

PIFEX MODULES SHOWING BRANCHING FROM ONE MODULE

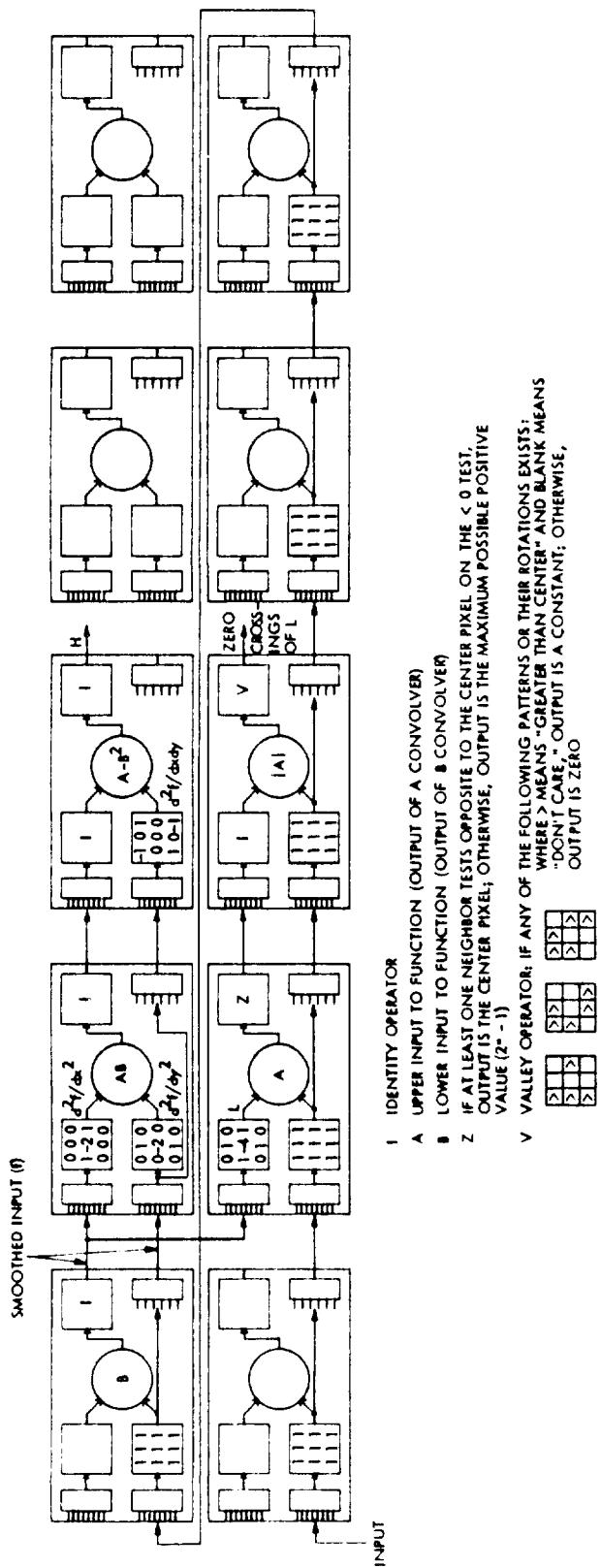


A B

TWO REPRESENTATIONS OF INTERCONNECTION TOPOLOGY

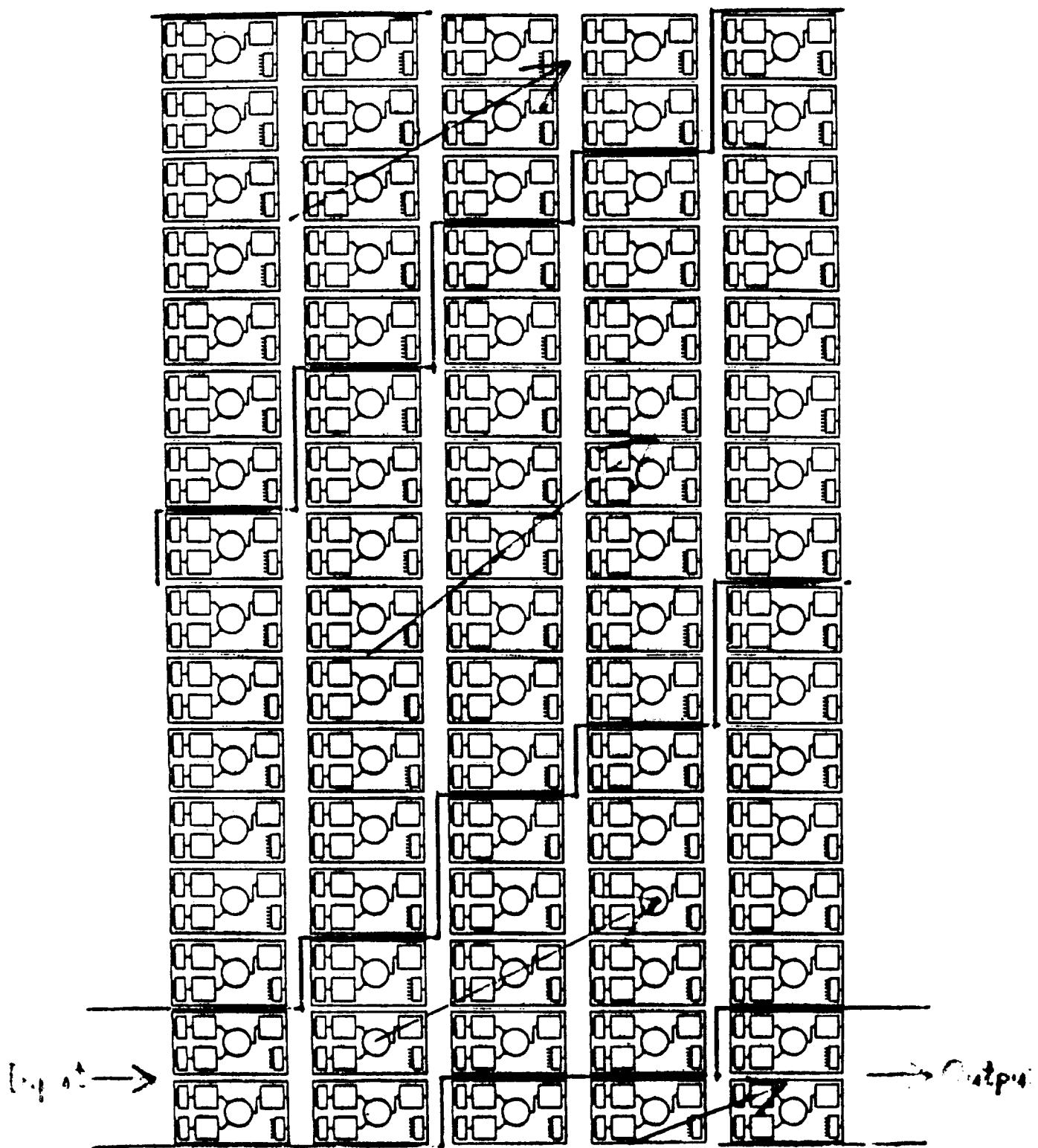


→ DIRECTION OF MAIN DATA FLOW (ALONG ROWS)
--- CUT FOR INPUT AND OUTPUT (ALONG A COLUMN)

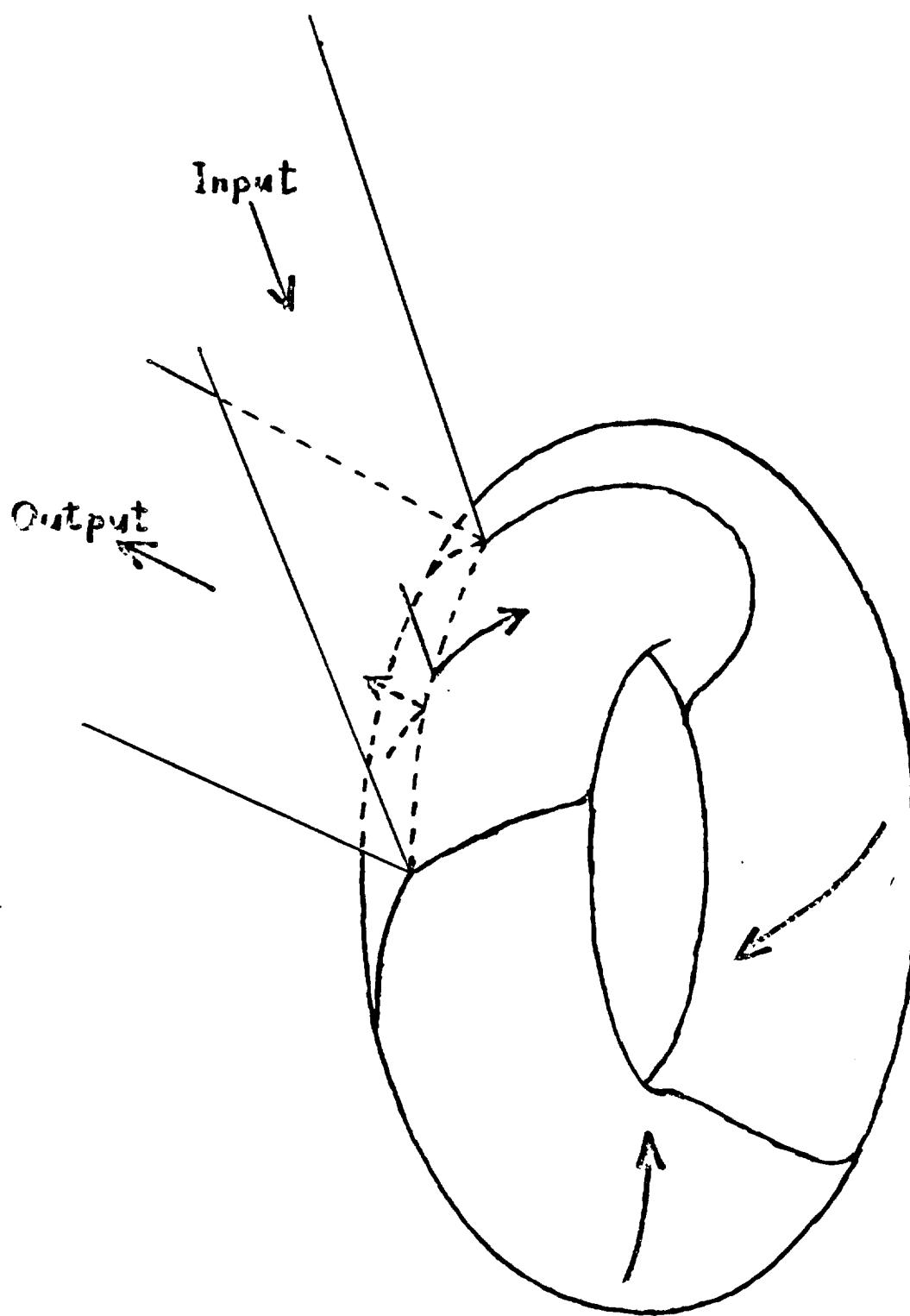


Computation of Hessian and zero crossings of Laplacian
(using approximate Gaussian smoothing with $\sigma = 2$)

EXAMPLE OF WRAP-AROUND



EXAMPLE OF WRAP-AROUND





PIFEX USES AND OVERVIEW

EACH MODULAR CARD DOES:

- 200 MILLION OPERATIONS/SECOND
- 2 CUSTOM VLSI 3x3 CONVOLVERS- SMOOTHING, DERIVATIVES, ETC.
- LOOK-UP TABLE FOR ARBITRARY OPERATIONS
- NEIGHBORHOOD COMPARISON- MAX, MIN, RIDGE, ETC.

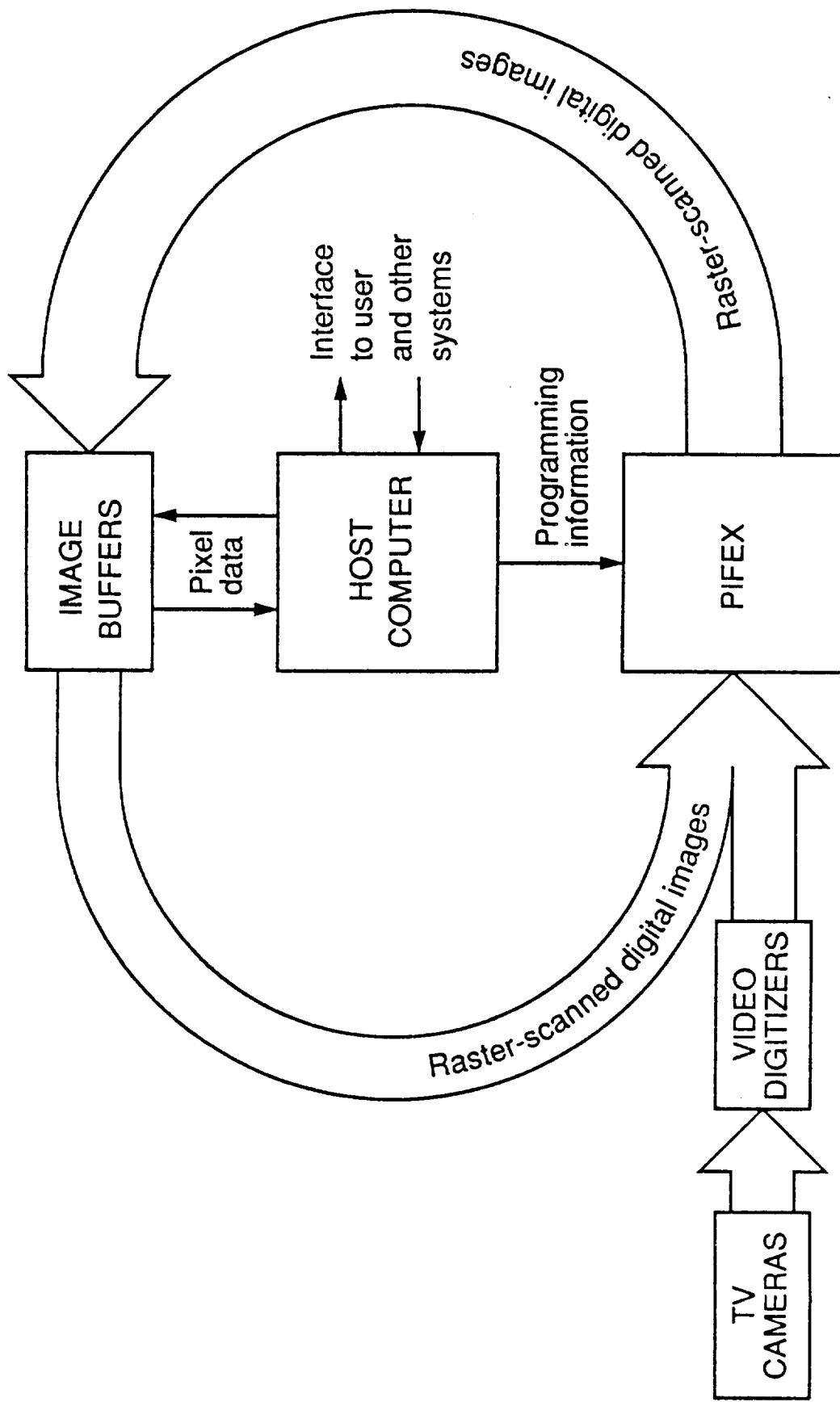


PIFEX USES AND OVERVIEW (CONTINUED)

A LARGE ARRAY OF MODULAR CARDS:

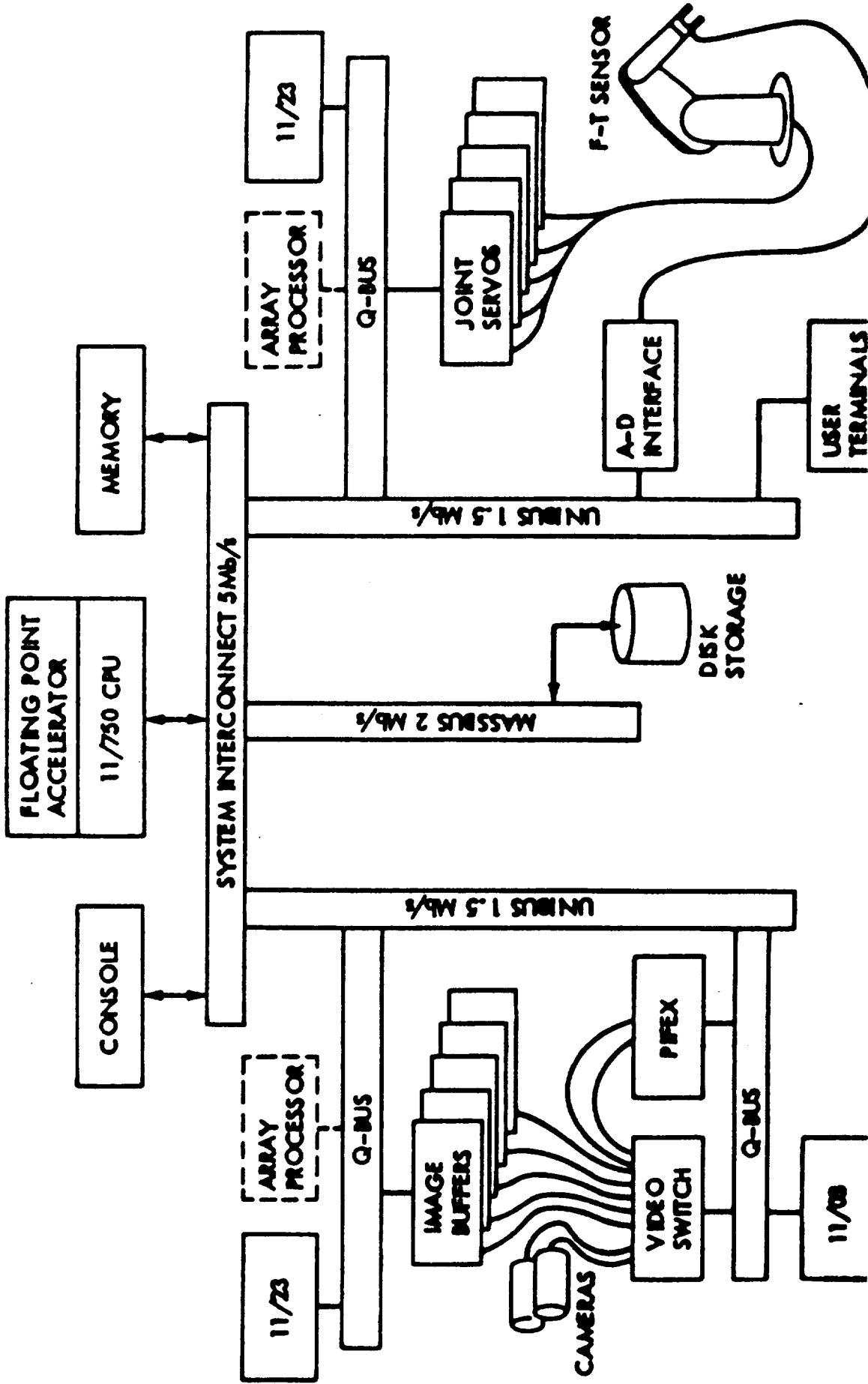
- 100 BILLION OPERATIONS/SECOND (500 CARDS)
- EXTRACT FEATURES FROM IMAGES IN REAL-TIME:
EDGES, VERTICES, ETC. (1-100 CARDS)
- DO REAL-TIME STEREO CORRELATION OF IMAGE PAIRS
(2000-5000 CARDS, DEPENDING ON ALGORITHM SOPHISTICATION)
- PRODUCE SIMULTANEOUS DEPTH DISCONTINUITY, TEXTURE
BOUNDARY, AND OBJECT MOTION MAPS (500-1000 CARDS)
- SOLVE MANY OTHER TWO-DIMENSIONAL PROBLEMS
(DIFFERENTIAL EQUATIONS, ROUTE PLANNING)

VISION SYSTEM



JPL

COMPUTER VISION AND ROBOT CONTROL
LABORATORY SYSTEM ARCHITECTURE
(FY84 AND BEYOND)



1022



FEATURE EXTRACTION AND ROVER WORK AT JPL

- MARS ROVER - 50 WORK YEARS FROM '73 TO '79
- TRACKING DESIGNATED OBJECTS IN STEREO
- VEHICLE PATH PLANNING FROM RANGE MAP
- COORDINATE OTHER ACTIONS WITH VEHICLE (E.G. MANIPULATOR)

- IMAGE FEATURE EXTRACTOR (IMFEX)- '78 TO '84
- 100 MILLION OPERATIONS PER SECOND
- IMAGE EDGE MAPS AT 60 Hz

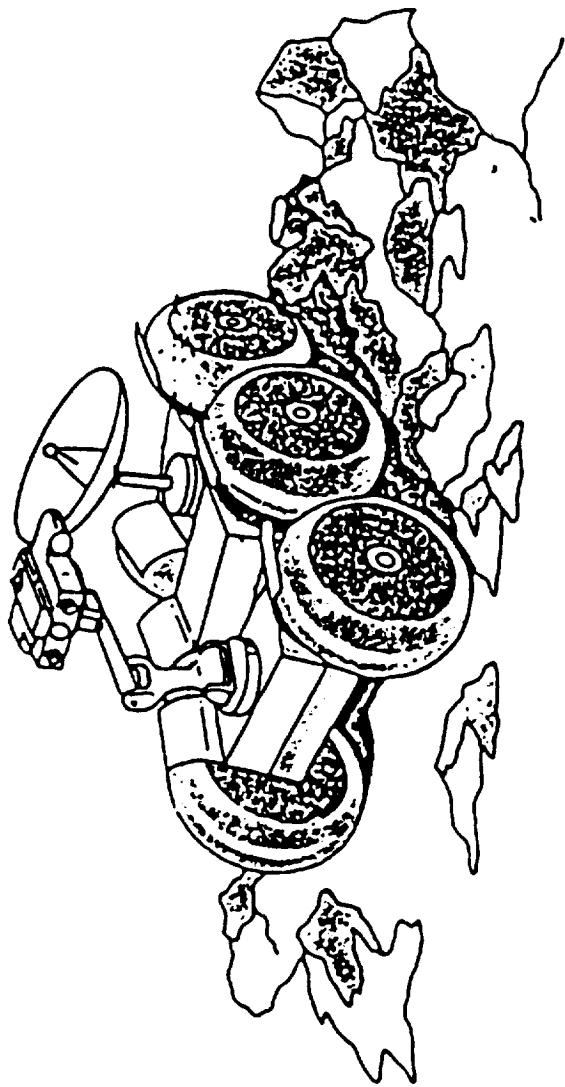
- PROGRAMMABLE IMAGE FEATURE EXTRACTOR (PIFEX)- CURRENT WORK STARTED '83
- MODULAR ARCHITECTURE EXPANDABLE TO 100 BILLION OPERATIONS/SEC OR MORE
- REAL-TIME RANGE MAPPING, TEXTURE BOUNDARIES, DEPTH DISCONTINUITIES, ETC.
- OTHER TWO-DIMENSIONAL PROCESSING: E.G. PATH PLANNING



MINIMAL MARS ROVER CONTROL SCENARIO

- ROVER TRANSMITS PANORAMA FROM STEREO CAMERAS TO EARTH
- HUMAN OPERATOR DESIGNATES 10-100 METER PATH IN 3-D DISPLAY
- HUMAN OPERATOR DESIGNATES PROMINENT VISUAL FEATURES FOR ROVER OPTICAL VERIFICATION OF PATH TRAVERSAL
- PATH SEGMENT LENGTHS, TURN ANGLES, AND CONFIRMING FEATURE LOCATIONS TRANSMITTED TO ROVER
- ROVER TRAVERSES PATH, CONTROLLED BY ODOMETER, GYRO, AND VISUAL FEATURE TRACKING
- ROVER TRANSMITS ANOTHER PANORAMA UPON PATH COMPLETION OR ERROR

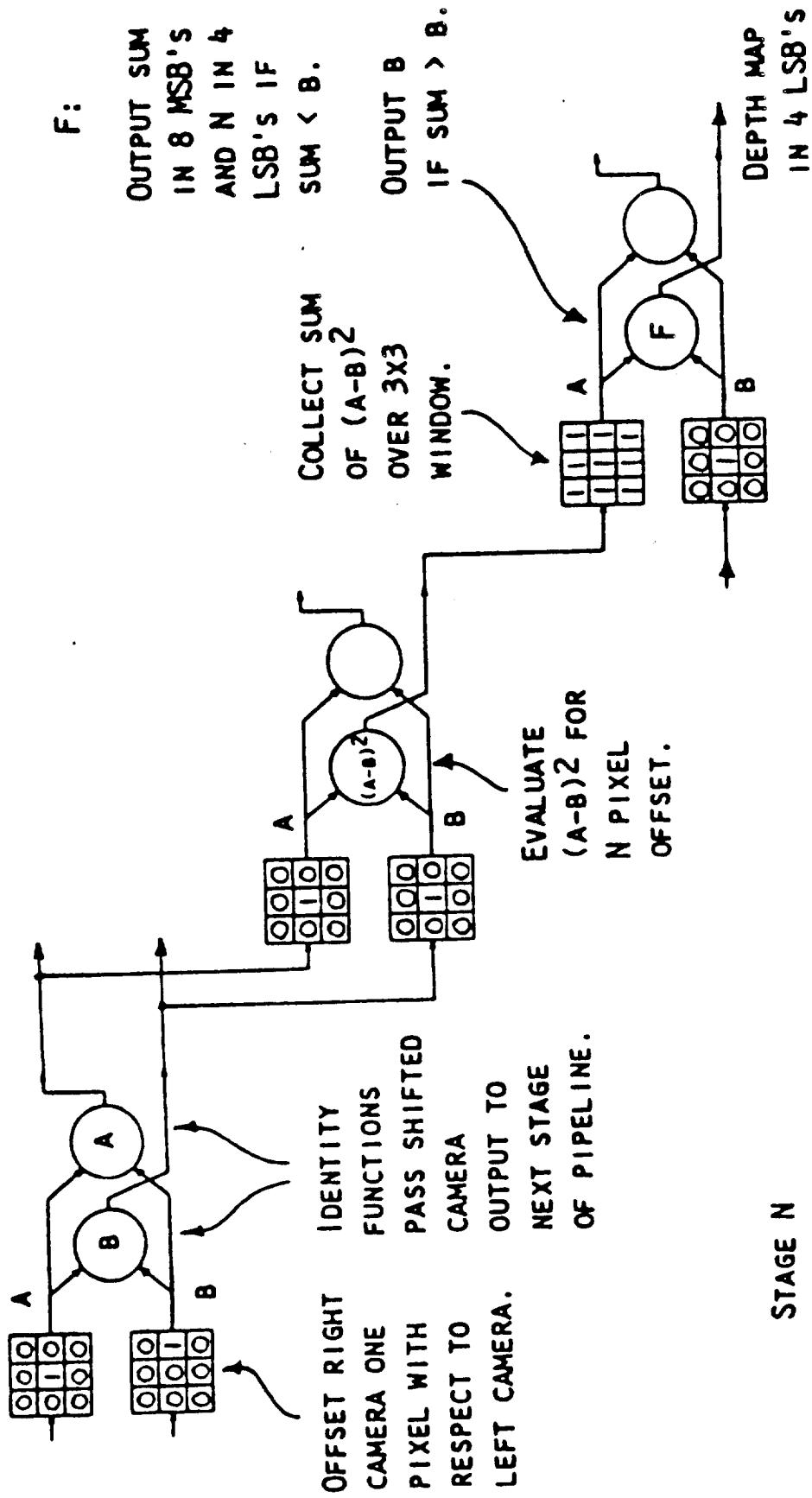
CONCURRENT PROCESSING APPLIED TO ROVER PATH PLANNING



- REDUCE STEREO IMAGERY TO RANGE MAP-- PIFEX
- ASSIGN SYMBOLIC NAMES, SIZES, ETC TO EXTRACTED RANGE MAP FEATURES
(E.G. DEPTH DISCONTINUITY OUTLINE-- CONCAVE UPWARD IS "HOLE",
CONCAVE DOWNWARD IS "OBSTACLE")
- TRANSFORM RANGE MAP INTO OBSTACLE LOCATIONS ON PLAN VIEW
- PLAN PATH AROUND OBSTACLES TOWARD GOAL



CREATING A REAL-TIME DEPTH MAP WITH PIFEX



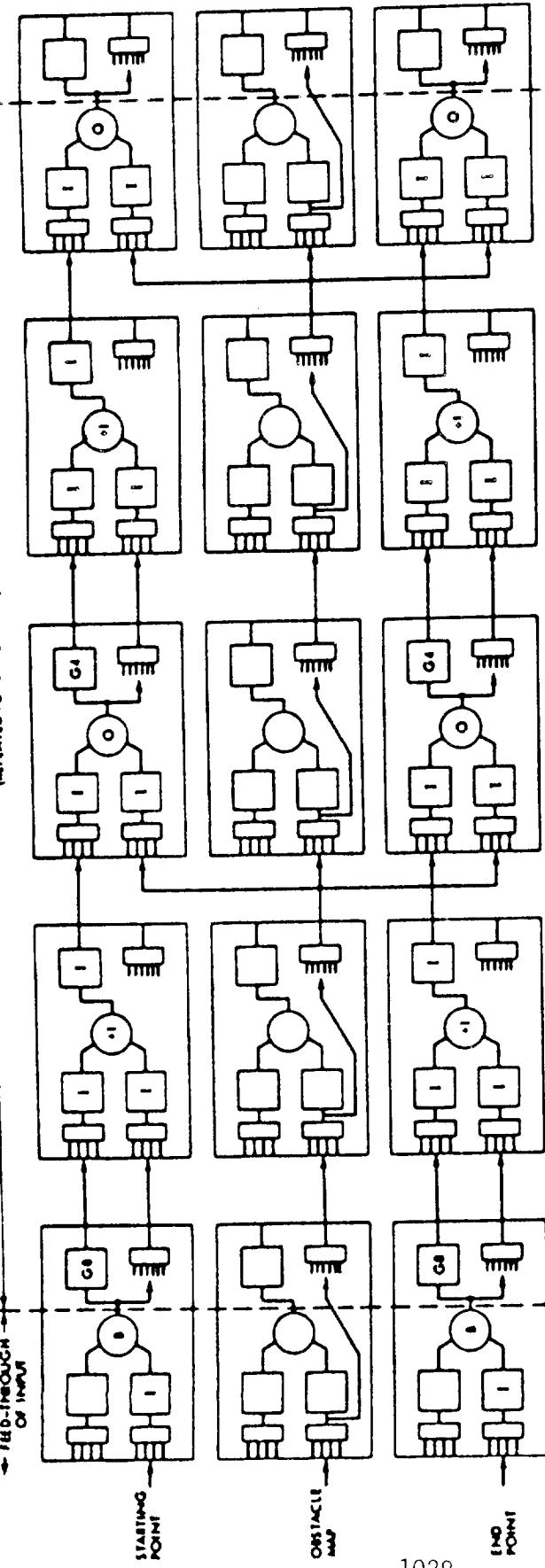
PIFEX APPLICATION TO ROUTE PLANNING

- BASED ON WITKOWSKI ALGORITHM (IJCAI-83)
- MIXED FIXED, MOVING OBSTACLES
- OBSTACLES WITH UNCERTAIN VELOCITY
- EXAMINES ALL POSSIBLE PATHS IN A 2000x2000 MAP IN 10 SECONDS (WITH 400 PIFEX CARDS; TAKES 5 DAYS ON A VAX)





INITIAL THROUGH INPUT
→



IDENTITY OPERATOR

UPPER INPUT TO FUNCTION OUTPUT OF A COMMUTER
LOWER INPUT TO FUNCTION OUTPUT OF A COMMUTER

G4 FOUR-NEIGHBOR GROWTH OPERATOR, LOGICAL OR OF NEIGHBORS IF AT LEAST ONE OF NEAREST FOUR = 1, OTHERWISE ZERO

G8 EIGHT-NEIGHBOR GROWTH OPERATOR, LOGICAL OR OF EIGHT NEIGHBORS
IF $S = 0$ AND $A = 0$, THEN OUTPUT $A + 1$, OTHERWISE OUTPUT ZERO

O OBSTACLE FUNCTION-
0 IF $S = 0$, THEN OUTPUT A , OTHERWISE OUTPUT ZERO

jpl →

ON-BOARD PROCESSING FOR MARS ROVER

- REDUCE LAB COMPUTING ENVIRONMENT TO FLIGHT HARDWARE -
500 MODULE PIFEX- 100 BILLION OPS/SEC
- VAX EQUIVALENT MICROPROCESSOR- 1-5 MOP/S
SYMBOLIC PROCESSOR 500-1000 LOGICAL INFERENCES/SEC
- MICROELECTRONICS IN 1992 -
1-10 MILLION COMPONENTS/CHIP
100 MHz BANDWIDTH
RAD-HARD CMOS, HMOS, Ga-AS

JPL

**JPL DEVELOPMENTS
IN
PLANNERS/OPERATIONS
AUTOMATION**

MAY 17, 1985

In this presentation a planning approach that is made up of a number of subprograms was described. These subprograms are called MI-TE-YU (micro computer-telephone conference displays), GREAT (graphic representation editing aid timeline), MOVIE (moving observation view interactive editor, "micro pointer" Execution Monitor), FAITH (forming and intelligently testing hypotheses), DEVISER (AI configuration planner), and PLAN-IT (AI schedule planner).

SVEN U. GRENANDER

JPL

AGENDA

- HISTORICAL PERSPECTIVE
- OBJECTIVES
- CURRENT TASKS
- SYSTEM INTEGRATION
- RESULTS

HISTORICAL PERSPECTIVE

- 1976 – MARS ROVER STUDY
VISION, MANIPULATORS AND AI
- 1980 – AI PLANNING
SOLUTION WITHOUT A PROBLEM
VIKING - VOYAGER SEQUENCING,
PROBLEM WITHOUT A SOLUTION
- POTENTIAL PROBLEM –
SOLUTION MATCH IDENTIFIED
- AI, MICROCOMPUTER TOOLS, COMPUTER GRAPHICS
COMPUTER COMMUNICATIONS, SYSTEMS
ENGINEERING

OBJECTIVES

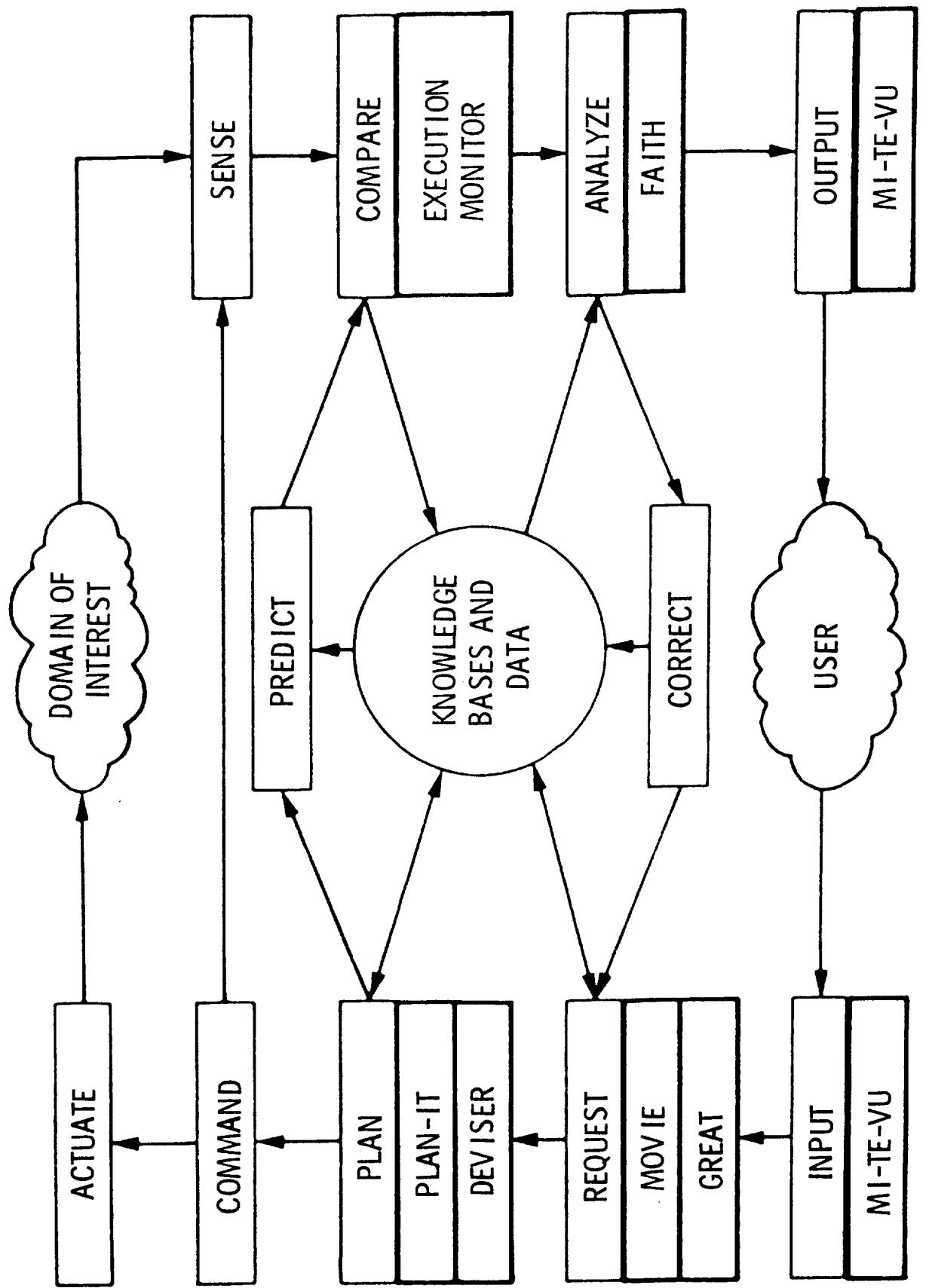
- SHORT / INTERMEDIATE TERM;
REDUCE COSTS OF MISSIONS INCREASE
RESPONSIVENESS OF MISSIONS
- LONG TERM;
PROVIDE COMPONENTS AND SYSTEMS ARCHITECTURE
FOR INCREASING DEGREES OF AUTONOMY

CURRENT TASKS

- MI-TE-VU (MICRO COMPUTER TELEPHONE CONFERENCED VUGRAPHS)
- GREAT (GRAPHIC REPRESENTATION EDITING AID TIMELINE)
- MOVIE (MOVING OBSERVATION VIEW INTERACTIVE EDITOR,
"MICRO POINTER")
- EXECUTION MONITOR (JUST THAT)
- FAITH (FORMING AND INTELLIGENTLY TESTING HYPOTHESIS)
- DEVISER (AI CONFIGURATION PLANNER)
- PLAN-IT (AI SCHEDULE PLANNER)

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UPCAT



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"MI-TE-VU" RESULTS

- USEFULLNESS PROVEN
- NEGOTIATING RECORDING IN "C"
- ACCEPTANCE HAMPERED BY HOST SELECTION

"GREAT" RESULTS

- BEING EXTENSIVELY USED BY VOYAGER
- CORE OF ULYSSES SEQUENCING SYSTEM
- BEING MODIFIED FOR GALILEO
- SPACELAB POTENTIAL TO BE EXPLORED
- ASSUMED FOR MMII BASELINE

"MOVIE" RESULTS

- BEING USED BY VOYAGER
- BEING RE-HOSTED FOR GALILEO
- HAS PROVEN MICRO-APPLICABILITY
TO MODERATE NUMBER CRUNCHING

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"EXECUTION MONITOR RESULTS"

- POTENTIAL BENEFIT RECOGNIZED
- VOYAGER TEST NEGOTIATED
- BEING TIED INTO DOWNLINK
LATE SUMMER OF 1985

"FAITH" RESULTS

- DEMONSTRATED ON SHUTTLE PROBLEM
(ONLY FOR VERIFICATION PURPOSES)
- DEMONSTRATED ON DIGITAL CIRCUIT PROBLEM
- DEMONSTRATED ON VOYAGER PPS EXAMPLE
- BEING TIED INTO EXECUTION MONITOR
FOR VOYAGER DEMONSTRATION

"DEVISER" RESULTS

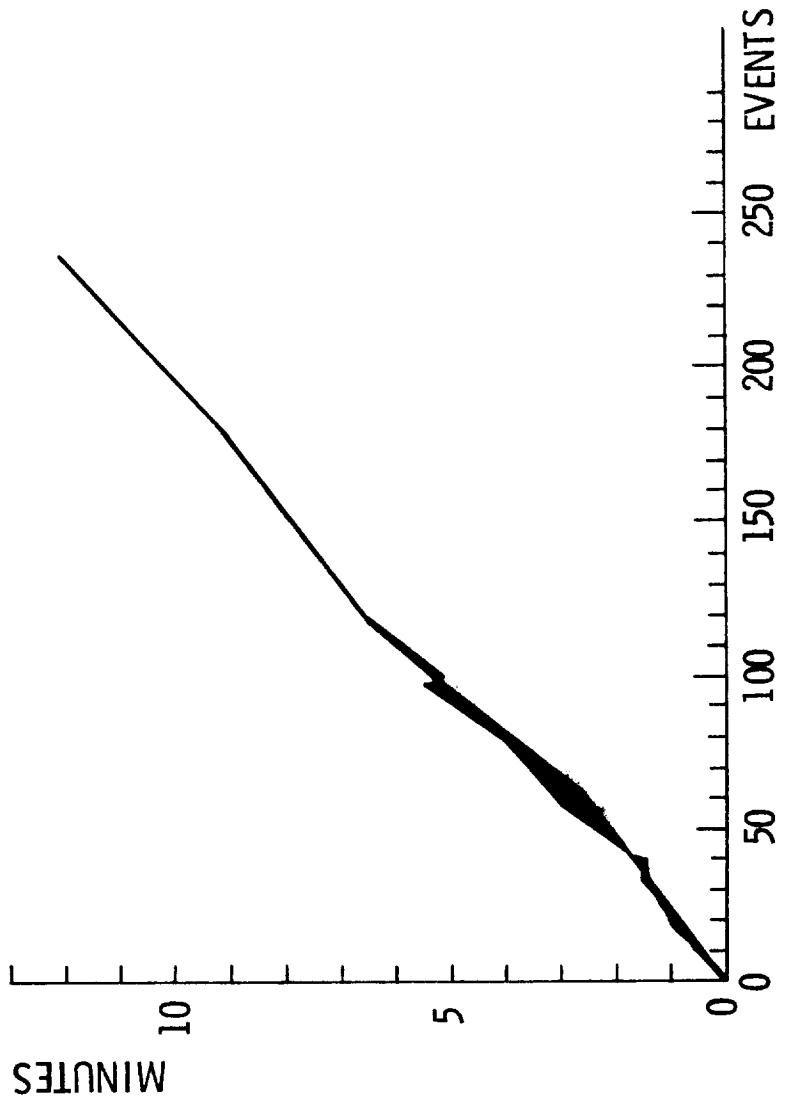
- DEMONSTRATED ON VOYAGER NEAR AND POST ENCOUNTER PLANNING
- NEEDS EXPERT OPERATOR OR COMPLEMENTARY SCHEDULE PLANNING CAPABILITY
- REASONABLE PERFORMANCE,
REASONABLE PLANS
 - 90 HIGH-LEVEL GOALS
IN 2.5 HOURS
APPROXIMATELY 300 ACTIVITIES

"PLAN-IT" RESULTS

- AN EXPERT SYSTEM FOR SCHEDULE PLANNING
- NOT A CONFIGURATION PLANNER (DEVISER)
- INTERNAL REPRESENTATION IN "T/L" FORMAT
 - Allows for time planning
- ALLOWS CAPABILITY GROWTH
- ALLOWS REAL-TIME T/L DISPLAY
- ALLOWS REAL-TIME USER INTERACTION
- WILL ALLOW INCORPORATION OF DEVISER-TYPE PLANNING CAPABILITY
- DEVELOPED FOR SPACELAB AND BEING APPLIED TO DSN AND SS POWER SYSTEM SCHEDULING

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PRELIMINARY PLAN-IT RESULTS



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05-17-85



AUTOMATED POWER SYSTEM CONTROL

PETER C. THEISINGER

SUPERVISOR, POWER SYSTEMS ENGINEERING GROUP

ELECTRIC POWER SYSTEMS SECTION

JET PROPULSION LABORATORY

This presentation addressed an approach to electrical power management that considers interactive load scheduling and component health assessment. The expert systems DEVISCR and PLAN-IT, described in the previous paper, are being proposed for this activity.



AREAS OF INVESTIGATION

- INTERACTIVE LOAD SCHEDULING/SEQUENCING REPLANNER
- COMPONENT HEALTH ASSESSMENT
- IDENTIFICATION OF OTHER POWER SYSTEM AREAS WHERE EXPERT OR RULE BASED SYSTEMS HAVE APPLICABILITY.

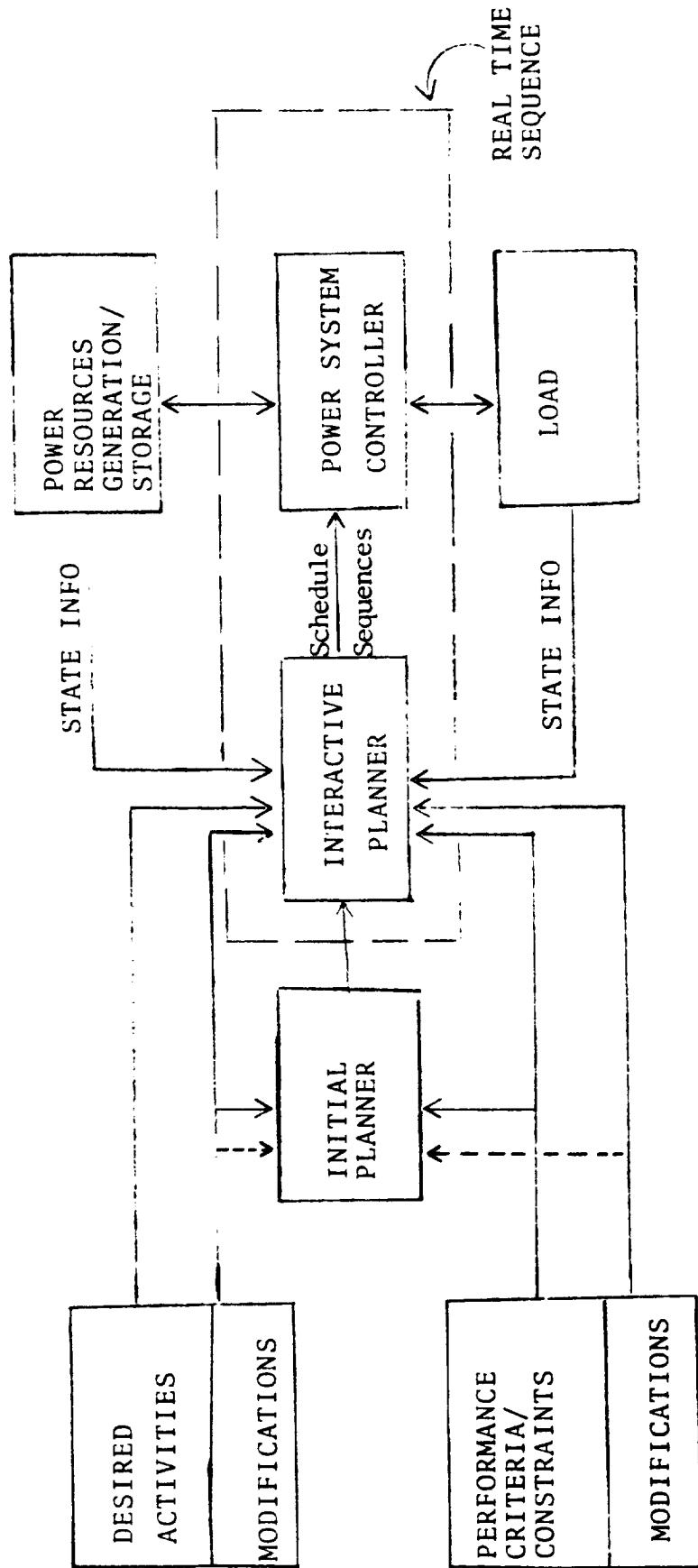


LOAD SCHEDULING/SEQUENCING

- GENERALLY PERCEIVED AS AN AREA OF HIGH PAYOFF FOR EXPERT SYSTEMS
- THREE LEVELS OF COMPLEXITY OR SOPHISTICATION
 - * INITIAL SEQUENCE GENERATION
 - * NEAR-REAL-TIME ("INTERACTIVE") SEQUENCE REPLANNING
 - * REAL TIME SEQUENCING CONTROL.



AUTONOMOUS POWER SYSTEM OPERATION
(CONCEPTUAL DIAGRAM)





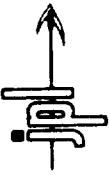
INITIAL SEQUENCE GENERATION

- TRADITION GROUND SEQUENCE PLANNING FUNCTION
- NOT TIME CONSTRAINED
- CURRENT TARGET FOR EXPERT SYSTEM APPLICATIONS
 - * "DEVISER"
 - * "PLAN-IT"



NEAR-REAL-TIME ("INTERACTIVE") SEQUENCE REPLANNING

- REQUIRED WHEN THE NOMINAL PLAN CANNOT BE ACCOMPLISHED BECAUSE OF REPRIORITIZATION, HARDWARE FAILURE, SUB-NORMAL HARDWARE PERFORMANCE.
- EXTREMELY TIME CONSTRAINED, WITH RESULTING CHANCES FOR ERROR AND LACK OF OPTIMIZATION.
- CURRENT TASK IS FOCUSING ON AN EXPERT SYSTEM IMPLEMENTATION FOR THIS FUNCTION
 - * PLAN IS TO DEVELOP A FEASIBILITY DEMO AS A FOLLOW-ON TO THE PLAN-IT DEVELOPMENT



REAL TIME SEQUENCING CONTROL

- EVOLUTION OF THE SEQUENCING TOOL TO A REAL TIME CONTROLLER
- IS A MICRO-MANAGING CONCEPT HEAVILY INTEGRATED WITH THE SYSTEM DESIGN AND ARCHITECTURE
- PRESENTLY CONSIDERED A CANDIDATE DEVELOPMENT FOR GROWTH STATION



COMPONENT HEALTH ASSESSMENT

- INCLUDES FAULT ISOLATION, FAULT DIAGNOSIS, TREND ANALYSIS
- CURRENT EFFORT TARGETED AT ENERGY STORAGE DEVICES:
 - INITIALLY BATTERIES, THEN RFC
- INITIAL GOAL IS TO DEVELOP A BATTERY MODEL CAPABLE OF
 - REPRESENTING DEGRADATION AND FAILURE MECHANISMS, THEN INCORPORATE THAT INTO AN EXPERT SYSTEM KNOWLEDGE BASE
- OBJECTIVE IS TO INCREASE REAL TIME KNOWLEDGE OF ENERGY STORAGE MECHANISM STATE OF HEALTH TO ALLOW REDUCED OPERATIONAL COVERAGE AND PROVIDE BETTER "RISK MANAGEMENT"

Wayne Zimmerman

This presentation described a study being sponsored by the Space Station Program Office (JSC managers are Norm Chaffee and Max Holley). The study has three subtasks. The first is simply to provide support to SE&I level C. The second subtask is to develop tools that support level B and level C trade-off activities, and assist in the evaluation of contractor autonomy plans resulting from phase B activity. The third subtask is to provide planning support to the ATAC.

SPACE STATION SE & I AUTONOMY / AUTOMATION

TASK MANAGER
L. MILLER

TECHNICAL TASK MANAGER
WAYNE ZIMMERMAN



JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

In accordance with the guidelines provided for this information exchange, this presentation will explain the purpose of each of the task elements in the Autonomous Systems Engineering (SE&I) Task, the technical results of each element, summary, and applications of the task results to the Phase B engineering master schedule.

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OVERVIEW

- EXPLAIN PURPOSE OF TASK ELEMENTS AND HOW ELEMENTS SUPPORT JSC SE&I AUTONOMY EFFORT
- PROVIDE TECHNICAL RESULTS FOR EACH TASK ELEMENT
 - SUMMARY
 - APPLICATIONS

The Autonomous System Engineering Task is funded by NASA, JSC under UPN No. 483-32-05-01. The JSC technical area managers responsible for (SE&I) this task are Max Holley and Norm Chaffee. The major subtasks are: (1) detailed support to the Level B SE&I Autonomy effort, (2) supporting studies (i.e., the development of SE&I automation evaluation tools), and (3) planning support to the Level B technology implementation effort. In addition to the Level B technology implementation work, this task area also provides ad hoc support to the ATAC.

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AUTONOMOUS SYSTEMS ENGINEERING (SE&I)
INFORMATION EXCHANGE - MAY 17, 1985

AUTONOMOUS SYSTEMS ENGINEERING TASK: UPN 483-32-05-01
JSC SE&I MANAGERS: N. CHAFFEE/M. HOLLEY

SUBTASKS:

- 1 DETAILED SUPPORT TO LEVEL B SE&I IN AREA OF AUTONOMY/AUTOMATION
- 2 SUPPORTING STUDIES (MAN-MACHINE TRADE-OFFS AND SUBSYSTEM FUNCTION PARTITIONING)
- 3 PLANNING SUPPORT TO LEVEL B/ADVANCED TECHNOLOGY ASSESSMENT
(ATAC PLAN INPUTS)

Having explained the basic task makeup, it is important to state how this task fits into the overall SE&I and Phase B program structure. First, the supporting studies (human-machine tradeoff analysis) provide the workpackages with a means of identifying the key variables and tradeoffs involved in selecting automation functional candidates and supporting technologies. The Level B technology implementation work not only supports the process of conducting technology trades, but also provides more depth for the workpackages when: (1) identifying likely IOC/growth automation technologies, and (2) projecting needed resources for technology implementation.

IMPORTANCE OF TASK TO LEVEL B/LEVEL C

- HUMAN-MACHINE AUTOMATION TRADEOFF METHODOLOGY
- PROVIDES WORKPACKAGES WITH MEANS OF RECOGNIZING MAJOR VARIABLES/TRADEOFFS INVOLVED IN SELECTING AUTOMATION
- LEVEL B TECHNOLOGY FORECASTING/PLANNING STRUCTURE
- SUPPORTS BOTH TRADEOFF METHODOLOGY AND ATAC
- PROVIDES WORKPACKAGES WITH MEANS OF:
 - IDENTIFYING LIKELY IOC/GROWTH AUTOMATION TECHNOLOGIES
 - BREAKING DOWN GENERIC TECHNOLOGIES INTO DEVELOPMENT STEPS
 - PROJECTING RESOURCE REQUIREMENTS

The first task element, detailee support, is an on-going effort which started in mid-February. Presently, the JPL detailee has been providing technical and planning assistance to Level B in the area of Space Station autonomy/automation. Additional ad hoc support has been given to the detailee by request from the JPL SE&I automation team.

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**TASK ELEMENT I
DETAILEE TO LEVEL B SE&I**

- PURPOSE
 - DETAILEE TO PROVIDE SUPPORT TO JSC LEVEL B AUTONOMOUS SYSTEMS TECHNICAL AREA MANAGER
- STATUS
 - DETAILEE CANDIDATE SELECTED, ON SITE AT JSC AS OF FEBRUARY 17, AND PRESENTLY PROVIDING SE&I PHASE B TECHNICAL/PLANNING SUPPORT

The second major task element, supporting studies, was established primarily to help guide and assess Phase B workpackage automation judgements in the areas of human-machine functional allocations and applied technologies. In this part of the presentation, the human-machine automation tradeoff research will be discussed. Within the overall tradeoff design, several important components essential to both automation tradeoffs and the Level B technology implementation plan were studied and developed. These components include structures for: (1) automation functional allocations, (2) automation conceptual designs, (3) advanced technology costing, (4) consideration of the potential value of work hours saved on-orbit, and (5) automation cost/benefit assessment. At this time all of the tradeoff components have been developed and demonstrated. Each component, with an example application, is shown in the following viewgraphs.

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**TASK ELEMENT 2
SUPPORTING STUDIES**

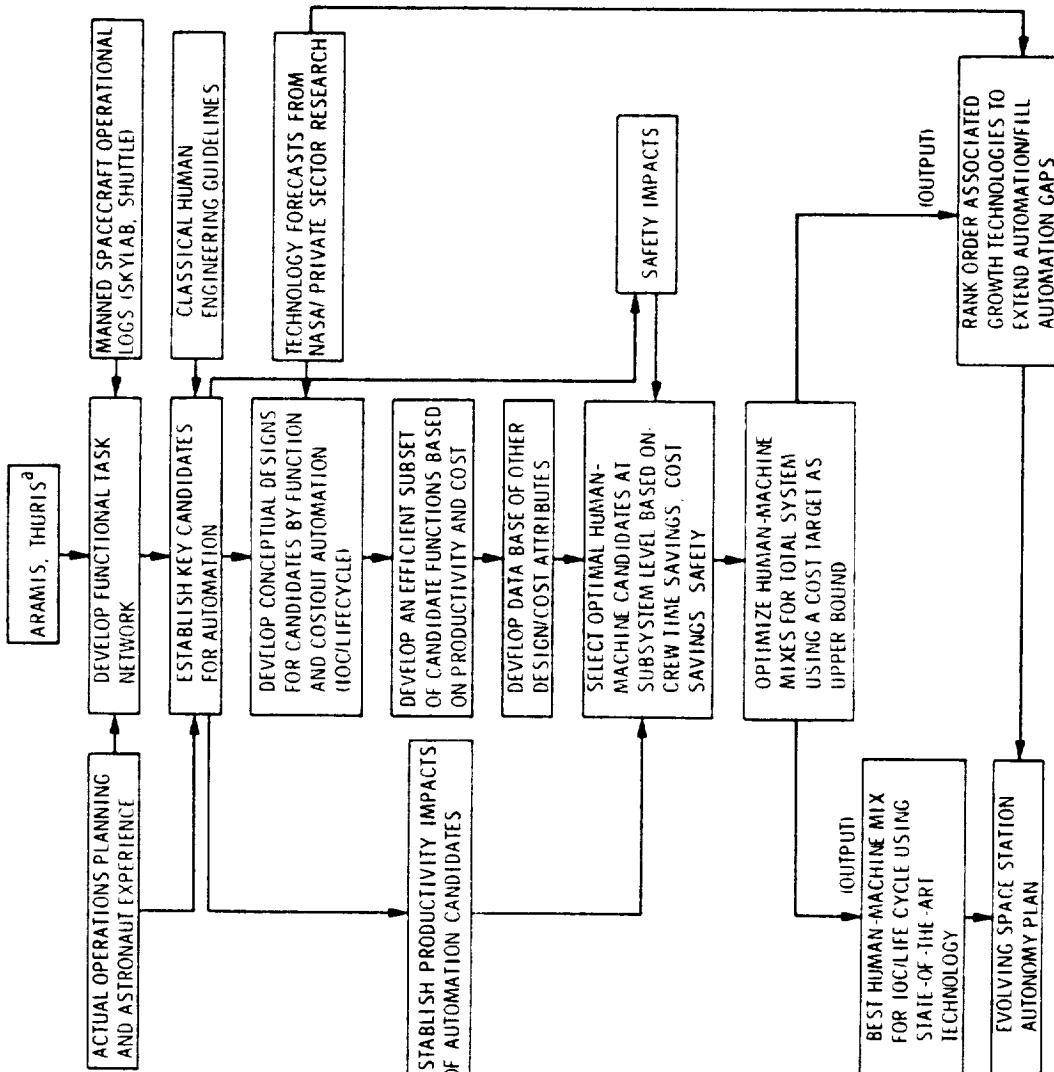
- PURPOSE: DEVELOP TOOLS/METHODOLOGIES THAT SUPPORT LEVEL B AND LEVEL C TRADE-OFF ACTIVITIES, AND ASSIST IN EVALUATION OF CONTRACTOR AUTONOMY PLANS RESULTING FROM PHASE B ACTIVITY. TOOLS INCLUDE:
 - HUMAN-MACHINE AUTOMATION TRADEOFF METHODOLOGY
 - STRAWMAN FUNCTIONAL ALLOCATIONS
 - AUTOMATION CONCEPTUAL DESIGNS
 - ADVANCED TECHNOLOGY COSTING
 - VALUE OF WORKHOURS SAVED
 - AUTOMATION COST/BENEFIT ANALYSIS

SUPPORTING STUDIES (CONT'D)

- TECHNICAL STATUS
 - HUMAN-MACHINE TRADEOFF METHODOLOGY PUBLISHED
(JPL PUBLICATION 85-13)
- PRELIMINARY AUTOMATION CANDIDATES IDENTIFIED FROM
RENDEZVOUS/DOCK FUNCTIONAL NETWORK EXAMPLE
- RENDEZVOUS/DOCK CONCEPTUAL DESIGN FOR AUTOMATION
COMPLETED; COSTING EXERCISE COMPLETED
- TRADEOFF MODEL DATABASE COMPLETED
- VALUE OF WORK-HOUR IN SPACE APPROXIMATED
- COST/BENEFIT ANALYSIS COMPLETED ON RENDEZVOUS/
DOCK (GN&C) EXAMPLE

As a lead-in to the rest of the presentation it is important to first discuss the basic automation tradeoff structure. The first step in the structure is the development of functional task networks. Keeping productivity as a major design driver, functional networks are crucial to understanding: (1) tasks normally performed by the crew; (2) which tasks, when automated, will have major impacts on streamlining spacecraft operations; and (3) potential exposure to hazards. The key automation candidates are picked by separating those tasks that are the most complex, repetitive, time intensive, and safety endangering. The third step is to develop conceptual designs for the automation candidates. Once developed, the designs are then costed. Initially, the complete array of potential automation candidates is trimmed by eliminating those candidates that are high cost and offer little productivity payoff. Once the costing has been completed and the best candidates picked, the optimization process can commence. The process is first performed at the subsystem level, followed by the system level optimization which considers system cost, weight, power, and safety constraints. Ultimately, the best system wide human-machine mix, along with the most cost/mission effective plan for advanced technology incorporation, leads to the final Space Station autonomy plan. Each of the above analytical steps are discussed in detail in the following viewgraphs.

MAN-MACHINE TRADEOFF METHODOLOGY STRUCTURE



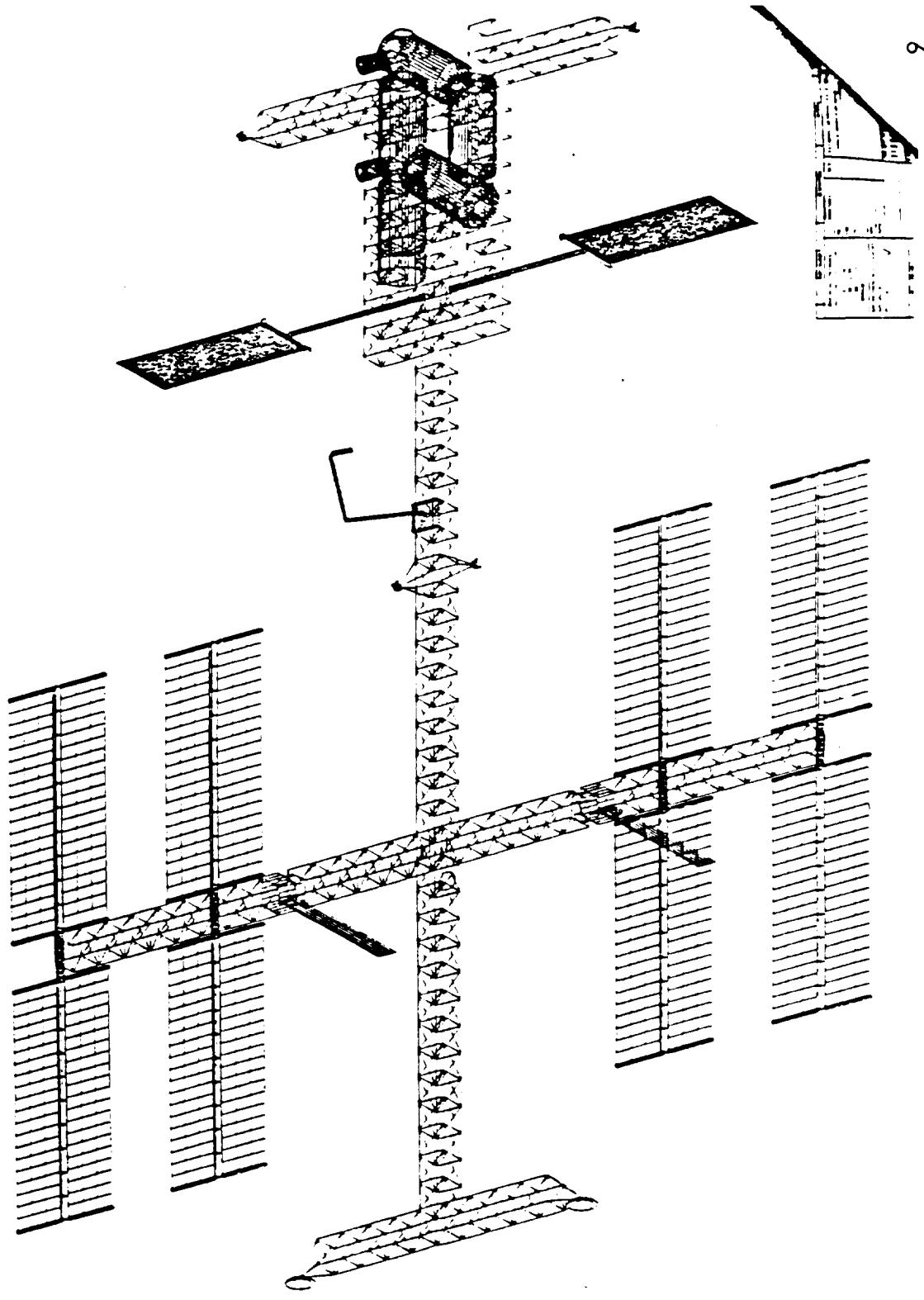
^a ARAMIS, Automation, Robotics Machine Intelligence Systems (MIT)
THURIS, The Human Role in Space (Marshall Space Flight Center).

The functional network analysis steps were explained clearly in the previous overview of the tradeoff structure. It is important to state that the reference configuration used in this study is the power tower design included in the Space Station Requirements document. To demonstrate the network analysis steps, the GN&C subsystem was selected along with a detailed breakdown of the rendezvous and docking function. Because a fairly straightforward, low-cost example was originally picked for the first test of the methodology in JPL Publication 85-13, it was decided to use a more complex example for this study to get a clearer idea of the spectrum of costs and benefits of automation. The complete rendezvous/docking network example is shown in viewgraphs 10 through 14.

- ESTABLISH REFERENCE CONFIGURATION FOR SYSTEM
- IDENTIFY EXISTING HARDWARE/CREW FUNCTIONS
 - MANNED SPACE PROGRAM EXPERIENCE
- PLACE FUNCTIONS IN APPROPRIATE PARALLEL/SERIES ORDER TO FORM NETWORK
- IDENTIFY CRITICAL FUNCTIONS (AUTOMATION CANDIDATES) BASED ON:
 - PRODUCTIVITY/OPS STREAMLINING
 - COMPLEXITY
 - SAFETY
 - REPETITIVENESS
 - CONCURRENCY

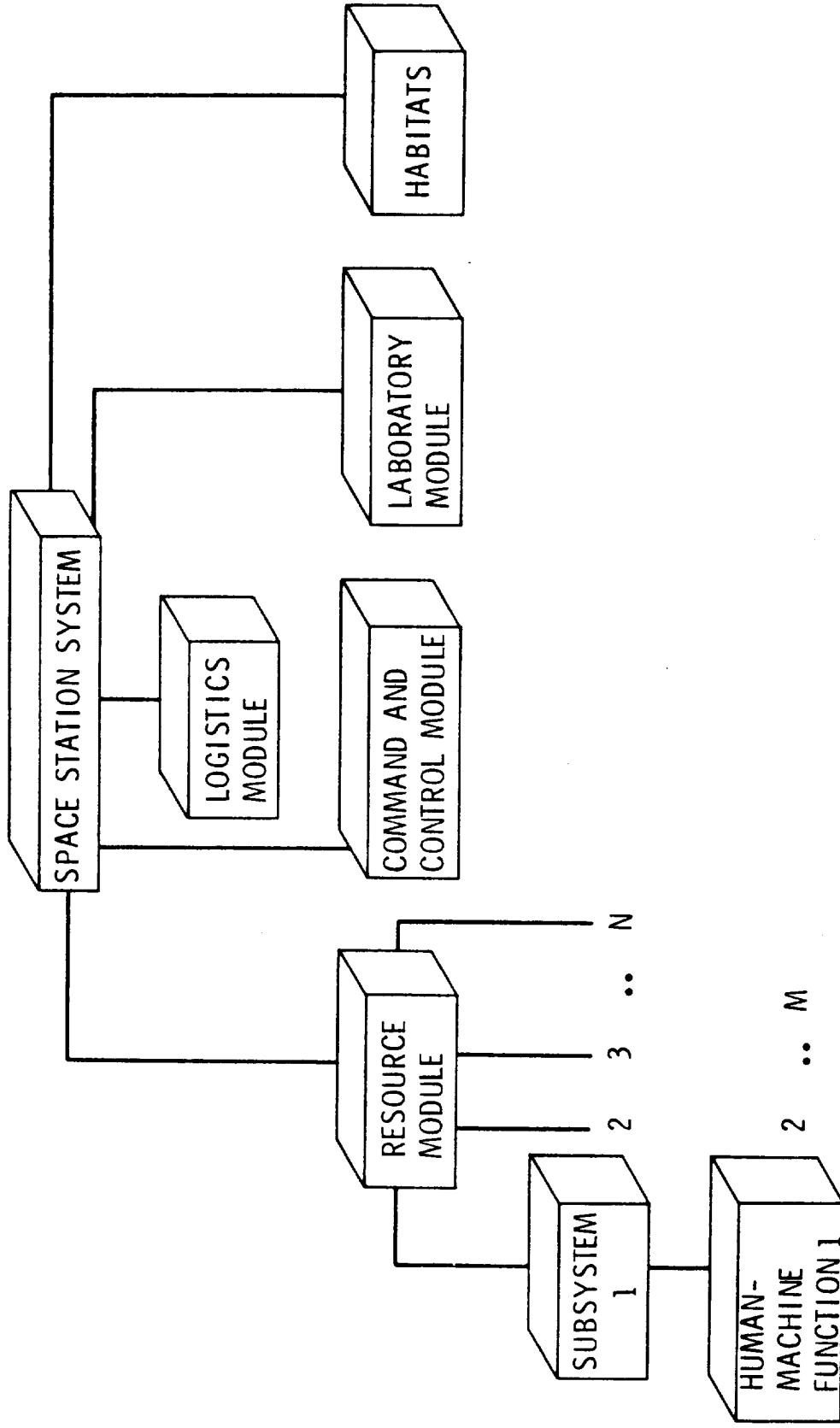
JPL

STRAWMAN SPACE STATION CONFIGURATION

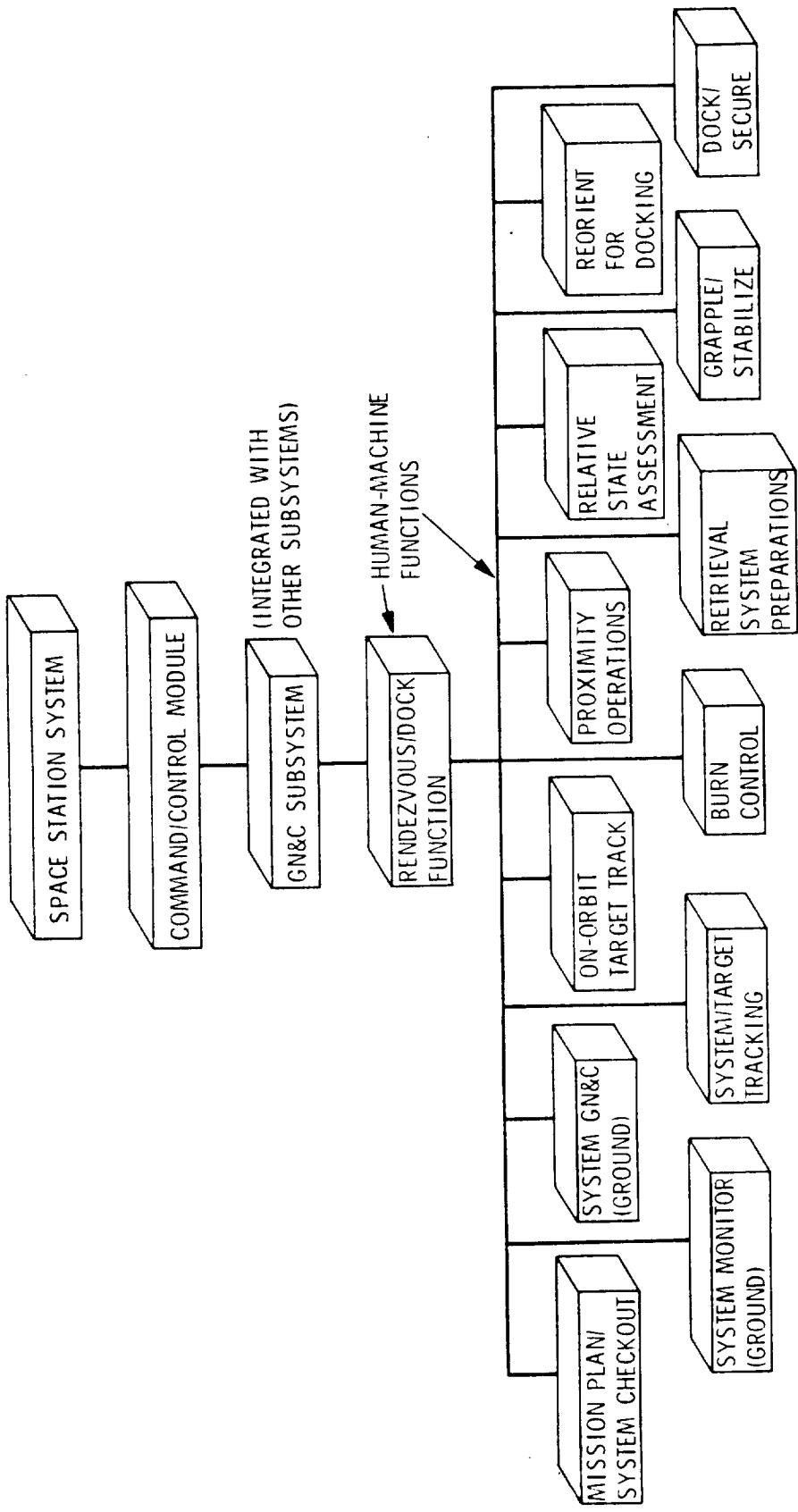


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OVERVIEW OF MODELED SPACE STATION SYSTEM



GN&C RENDEZVOUS/DOCKING EXAMPLE



RENDEZVOUS/DOCKING NETWORK RESULTS

- KEY TOP LEVEL AUTOMATION CANDIDATE FUNCTIONS OF OVERALL NETWORK
 - RENDEZVOUS
 - PLANNING
 - ORBIT TRANSFER (EXECUTION)
 - ORBIT TRIM (STATIONKEEPING)
 - TERMINAL RENDEZVOUS
 - PLANNING
 - COMMANDED TRANSLATION OF SHUTTLE, OMV, PLATFORM, ETC.
 - BERTHING
 - TRAFFIC CONTROL
 - ATTACHMENT PREPARATION (E.G., USING MANIPULATORS)
 - DOCKING
 - INITIATION (FINAL ALIGNMENT)
 - ATTACHMENT (HARD DOCK/TRANSIENT MOTION SUPPRESSION/ DATA AND COMMUNICATION LINKUP)

- KEY TOP LEVEL AUTOMATION CANDIDATE FUNCTIONS OF OVERALL NETWORK
 - PRE EVA
 - EVA EQUIPMENT CHECKOUT
 - EMU CHECKOUT
 - EVA PREPARATION
 - MMU CHECKOUT
 - TOOL/COMPONENT SUPPORT PLANNING
 - EVA
 - CAMERA/TV SUPPORT
 - EVA TOOL/COMPONENT SUPPORT
 - MMU PROPELLANT MONITORING
 - RMS COORDINATION
 - RMS ASSISTANCE IN MOVING / DOCKING / SECURING OBJECT AND LINKING UP COMMUNICATION / SERVICING COMPONENTS

EVA NETWORK RESULTS IN SUPPORT OF DOCKING (CONT'D)

- POST EVA
- EMU POWERUP
- WATER/OXYGEN RECHARGE AND VERIFICATION
- SUIT DRYING/SEAL LUBRICATION
- EMU LiOH CARTRIDGE/BATTERY REPLACEMENT
- EMU POWERDOWN
- MMU BATTERY AND GN 2 RECHARGE

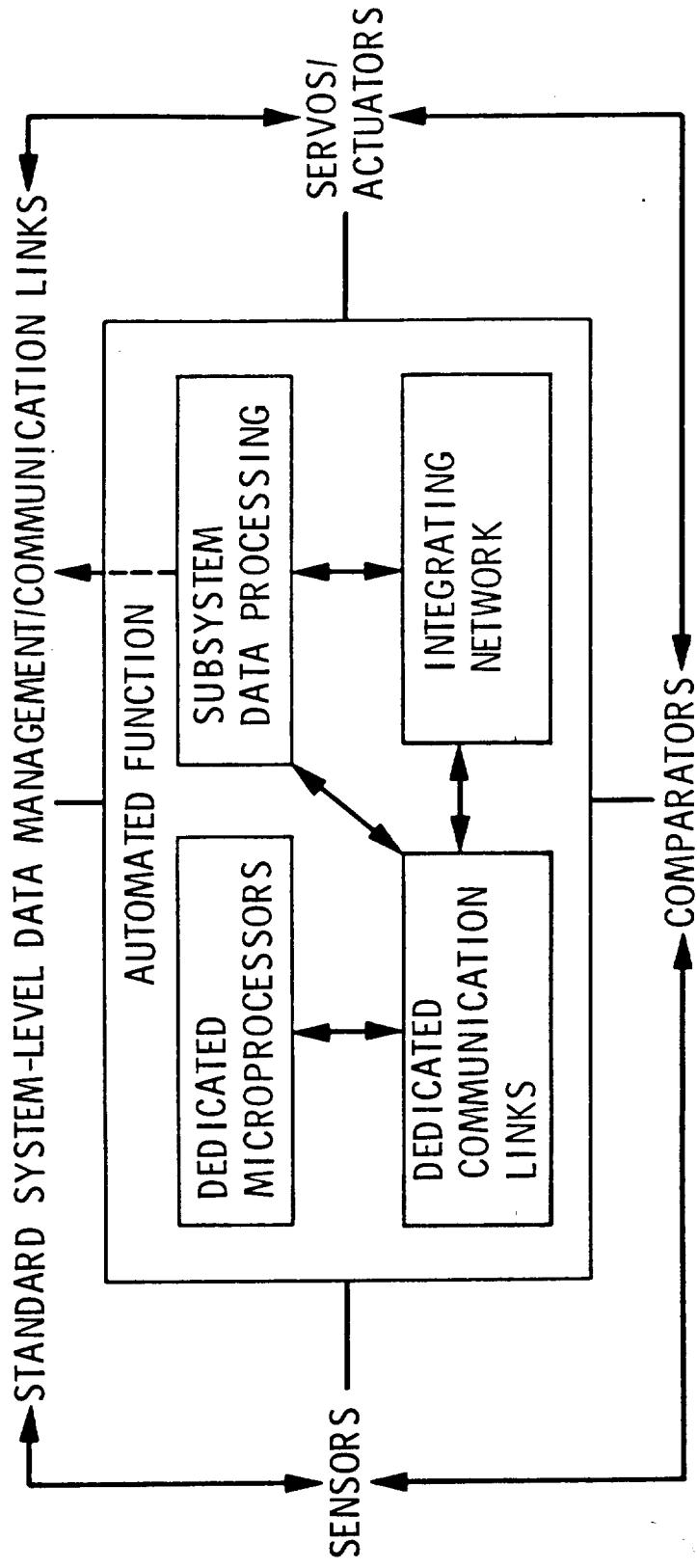
As shown earlier in the overall tradeoff structure, the conceptual design and costing steps follow the selection of the automation candidates. When developing a conceptual design, the functional network provides the designer with a means of breaking down functions into processes so the necessary hardware and software can be identified. Once this is done, the hardware (processors, sensors, etc.) and software can be assigned to each process. For purposes of being able to assess a wide array of potential automation candidates, it is generally easier to build/cost a conceptual design for total automation first. Once this is accomplished it becomes easier to separate functions and associated hardware/software, and to examine lesser degrees of automation. This process is done for all of the potential automation candidates before eliminating the high-cost, low-productivity alternatives. In the following viewgraphs the viewer, is first introduced to a generic automated system to show the basic components usually associated with an automated system. These components include dedicated microprocessors, integrating microprocessors, communication links, software, and any additional sensors required to replace the same human sensing capabilities. The generic automated system sets an important stage for understanding the costing approach used in this analysis. The basic approach is to examine the incremental cost increases/reductions in the baseline cost of a subsystem through the incorporation of automation.

After displaying a generic automated system, the viewer will see the application of the technique on the rendezvous/docking example. Viewgraphs 17 through 22 show the GN&C rendezvous/docking conceptual design, hardware/software descriptions, and potential costs. Interestingly enough, the choice of the more difficult rendezvous/docking problem resulted in an expansion of the costing portion of the methodology to include advanced automation. Although several different approaches were considered, ultimately it was decided that the best approach was to obtain the cost data from the organization actually performing the research. By knowing the yearly budget, and utilizing technology forecasts, the technology R&D and space qualification costs can be approximated. The rendezvous/docking GN&C automation package was projected at \$40 to \$50M.

CONCEPTUAL DESIGN/COSTING

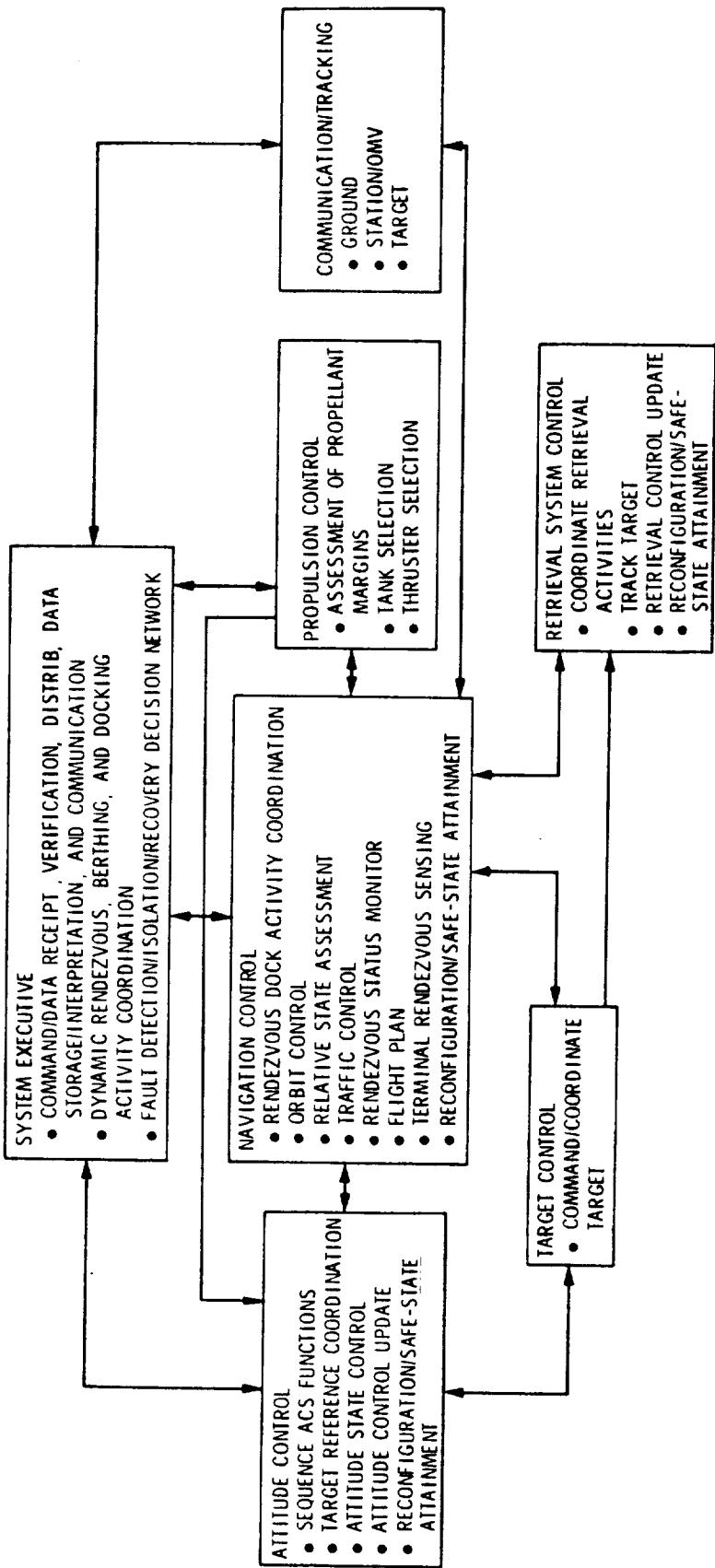
- BREAK DOWN FUNCTIONS INTO PROCESSES
- HARDWARE (SENSORS, MICROPROCESSORS, SERVOS, ETC.)
- SOFTWARE (CONTROL, VERIFICATION, FAULT-MANAGEMENT, ETC.)
- ASSIGN EXISTING HARDWARE/SOFTWARE TO EACH PROCESS
- ESTABLISH COST FOR A TOTALLY AUTOMATED SYSTEM USING STATE-OF-THE-ART TECHNOLOGY
- INITIALLY EXAMINE COST/PRODUCTIVITY FOR OPTIONS WITH VARYING DEGREES OF AUTOMATION (FROM 0 AUTOMATION → TOTAL AUTOMATION)
- ELIMINATE ALTERNATIVES EXHIBITING HIGH COST WITH LITTLE PRODUCTIVITY IMPROVEMENT

GENERIC AUTOMATED FUNCTION WITHIN A SUBSYSTEM



- CONCEPTUAL DESIGN FOR AUTOMATED FUNCTION MUST CONSIDER:
 - NUMBER OF DEDICATED MICROPROCESSORS/INTEGRATING NETWORKS
 - NUMBER OF DEDICATED COMMUNICATION LINKS/INTEGRATING COMMUNICATION LINKS
 - SOFTWARE REQUIREMENTS/COMPLEXITY
 - ADDITIONAL SENSORS/REDUNDANT PROCESSORS FOR OPERATION AND FAULT MANAGEMENT

AUTOMATED RENDEZVOUS/DOCKING CONCEPTUAL DESIGN (FUNCTIONS/PROCESSES)

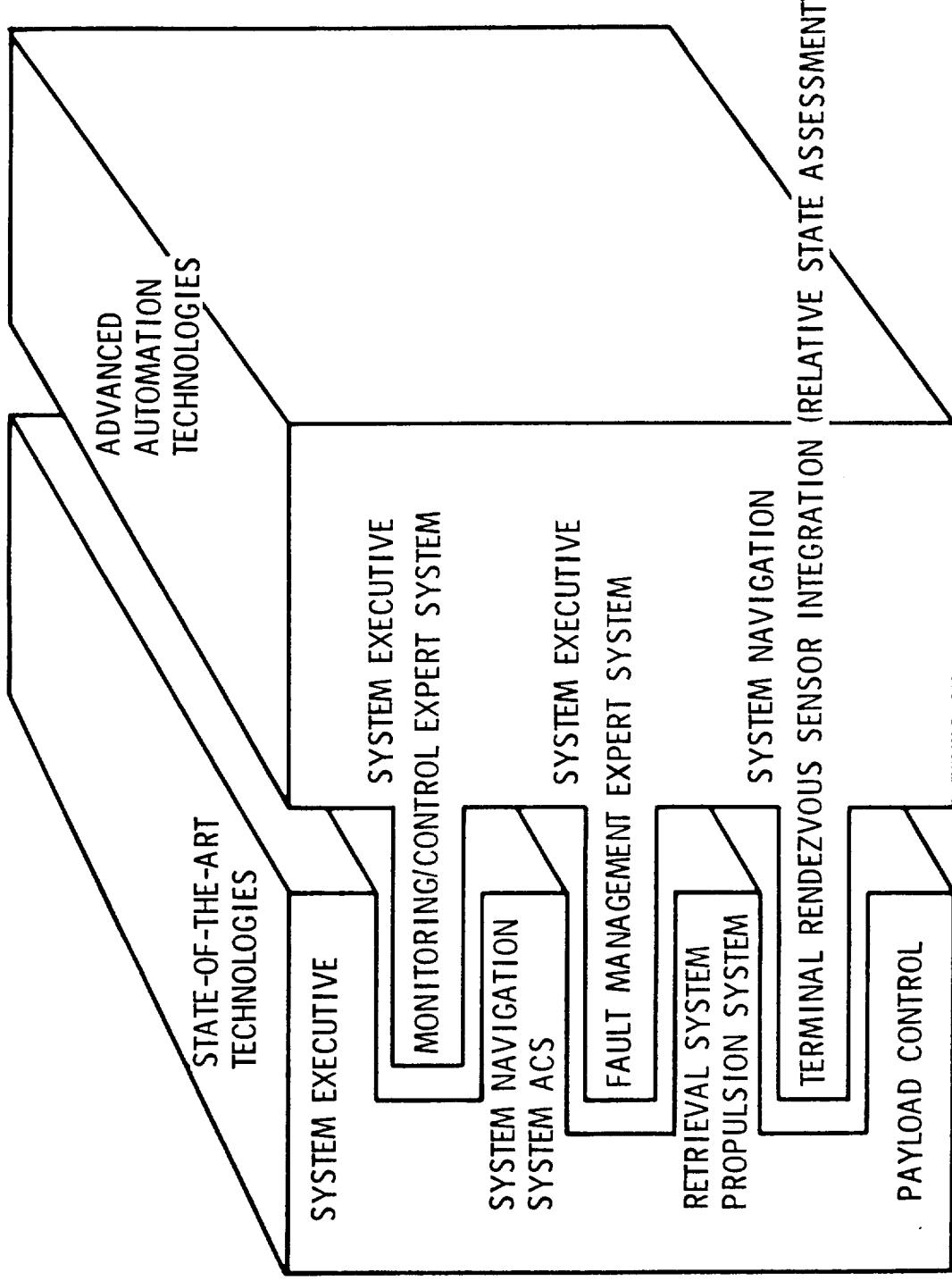


CONCEPTUAL DESIGN FUNCTION	HARDWARE	SOFTWARE	SUGGESTED SPARES
SYSTEM EXECUTIVE <ul style="list-style-type: none">• EXECUTIVE SERVICES• MONITORING• FAULT MANAGEMENT	INTEGRATING PROCESSOR INTEGRATING PROCESSOR INTEGRATING PROCESSOR	COMPLEX COMPLEX COMPLEX	2 2 2
ATTITUDE CONTROL <ul style="list-style-type: none">• EXECUTIVE SERVICES/FAULT MANAGEMENT• STATE CONTROL/UPDATE	INTEGRATING PROCESSOR INTEGRATING PROCESSOR	MODERATELY COMPLEX	2 2
NAVIGATION <ul style="list-style-type: none">• EXECUTIVE SERVICES/FAULT MANAGEMENT• ORBIT CONTROL• RELATIVE STATE ASSESSMENT• TRAFFIC CONTROL• STATUS MONITOR• FLIGHT PLAN• TERMINAL RENDEZVOUSSENSORS	INTEGRATING PROCESSOR INTEGRATING PROCESSOR DEDICATED PROCESSOR INTEGRATING PROCESSOR DEDICATED PROCESSOR DEDICATED PROCESSOR DEDICATED PROCESSOR	COMPLEX ESTABLISHED COMPLEX COMPLEX MODERATELY MODERATELY COMPLEX	2 2 2 2 2 2 2

HARDWARE/SOFTWARE (CONT'D)

CONCEPTUAL DESIGN FUNCTION	HARDWARE	SOFTWARE	SUGGESTED SPARES
TARGET CONTROL • COMMAND/COORDINATE TARGET	INTEGRATING PROCESSOR	MODERATELY COMPLEX	2
RETRIEVAL SYSTEM CONTROL • EXECUTIVE SERVICES/ FAULT MANAGEMENT	INTEGRATING PROCESSOR	COMPLEX	2
• TARGET TRACKING • CONTROL UPDATE	INTEGRATING PROCESSOR	COMPLEX	2
PROPELLION CONTROL • PROPELLANT PLANNER/THRUSTER CONTROL	INTEGRATING PROCESSOR	COMPLEX	2
COMMUNICATION/TRACKING	ESTABLISHED	ESTABLISHED	-

STATE-OF-THE-ART AND ADVANCED AUTOMATION
RENDEZVOUS/DOCKING TECHNOLOGIES



- STATE-OF-THE-ART TECHNOLOGY
 - COMMERCIAL SPACE QUALIFIED PROCESSOR/COMMUNICATION COMPONENTS (E.G., Z-80, 8086, 80286, 68000)
 - SOFTWARE [BOEHM SOFTWARE ENGINEERING ECONOMICS (COCOMO); ALLOWS SUBJECTIVE COMPLEXITY CRITERIA TO BE TRANSFERRED INTO "LINES-OF-CODE" RANGES]
- ADVANCED AUTOMATION TECHNOLOGY
 - AVAILABLE COMMERCIAL HARDWARE (I.E., PROCESSORS)
 - R&D/DESIGN COSTS FROM ACTUAL RESEARCH SOURCES
 - NASA CENTERS, UNIVERSITIES, AND PRIVATE SECTOR
 - TECHNOLOGY FORECASTS (PROVIDES NUMBER YEARS REQUIRED FOR R&D)
 - SUBSYSTEM/SYSTEM INTEGRATION AND SPACE QUALIFICATION COSTS

<u>TOTAL REQUIRED AUTOMATION TECHNOLOGIES</u>	<u>POTENTIAL COST RANGE</u>	
• SYSTEM NAVIGATION	\$22.6	- 24.5M
• ATTITUDE CONTROL SYSTEM	\$2.0	- 2.5M
• RETRIEVAL SYSTEM	\$10.9	- 13.6M
• PROPULSION CONTROL	\$0.5	- 0.7M
• PAYLOAD CONTROL	\$1.0	- 1.2M
• SYSTEM EXECUTIVE CONTROL	\$6.4	- 7.9M
TOTAL	\$ 43	- 50M
• ADVANCED TECHNOLOGIES		
• SYSTEM NAVIGATION (TERMINAL RENDEZVOUS SENSOR/SOFTWARE)	\$15.7	- 15.9M
• SYSTEM EXECUTIVE CONTROL		
• MONITORING/CONTROL	\$ 1.7	- 2.1M
• FAULT MANAGEMENT	\$ 3.5	- 4.4M

Once the conceptual design has been costed, the next step is to try to pick the best automation alternatives at the subsystem level. In order to accomplish this step, the net increase in subsystem cost due to automation must be weighed against potential savings in variables such as ground workforce, operator training, or operations and maintenance overhead. To make this assessment, a database was constructed reflecting existing private sector experience in system cost impacts (on variables such as workforce, maintenance, or spare components) as a function of the degree of automation employed. In building the database it was essential to select comparable systems based, most importantly, on similarity of functions. Other comparisons revolved around size, long life cycle, and complexity. The database contributors are listed for the viewer along with summary cost impact curves reflecting their joint experience. This information is provided in viewgraphs 23 through 30.

POTENTIAL AUTOMATION IOC/LIFE CYCLE COSTS/SAVINGS

COSTS

- AUTOMATION R&D/PRODUCTION^a
- GROUND MAINTENANCE
 - HARDWARE
 - SOFTWARE
- GROUND MAINTENANCE TRAINING
- MAINTENANCE TECHNICAL DOCUMENTATION

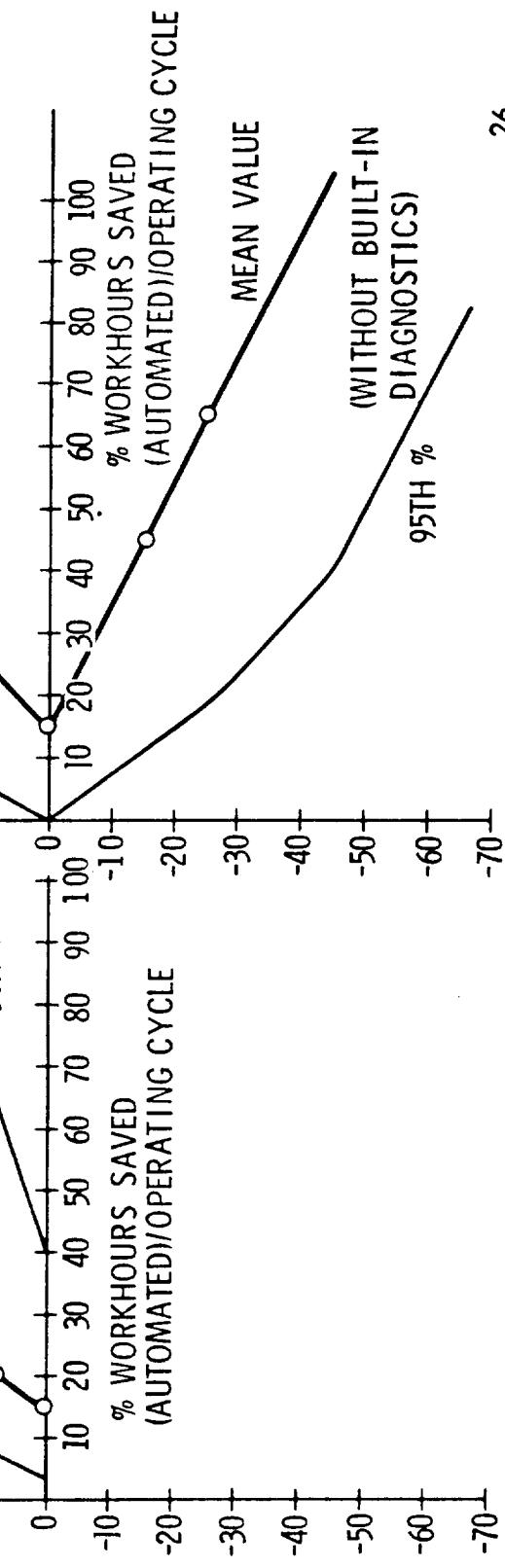
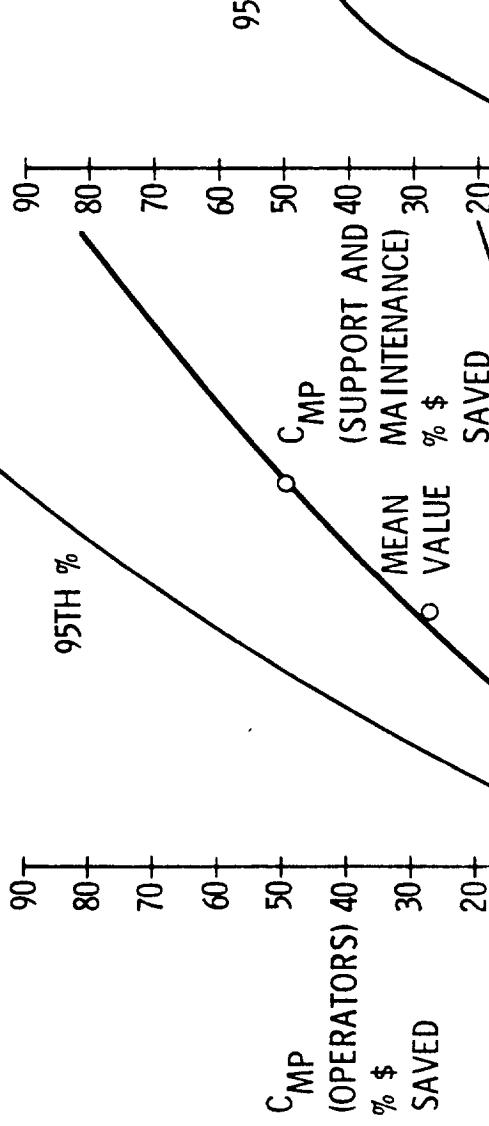
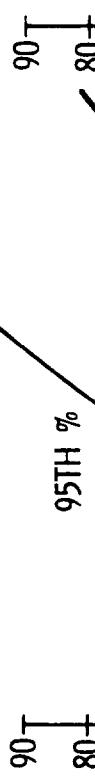
SAVINGS

- GROUND/STATION CREW OPERATIONS, TRAINING^a
- GROUND/STATION CREW OPERATIONS EFFICIENCY^a
- GROUND OPERATIONS FACILITIES^a
- GROUND SUPPORT AND TEST EQUIPMENT

^aAFFECTS IOC COSTS.

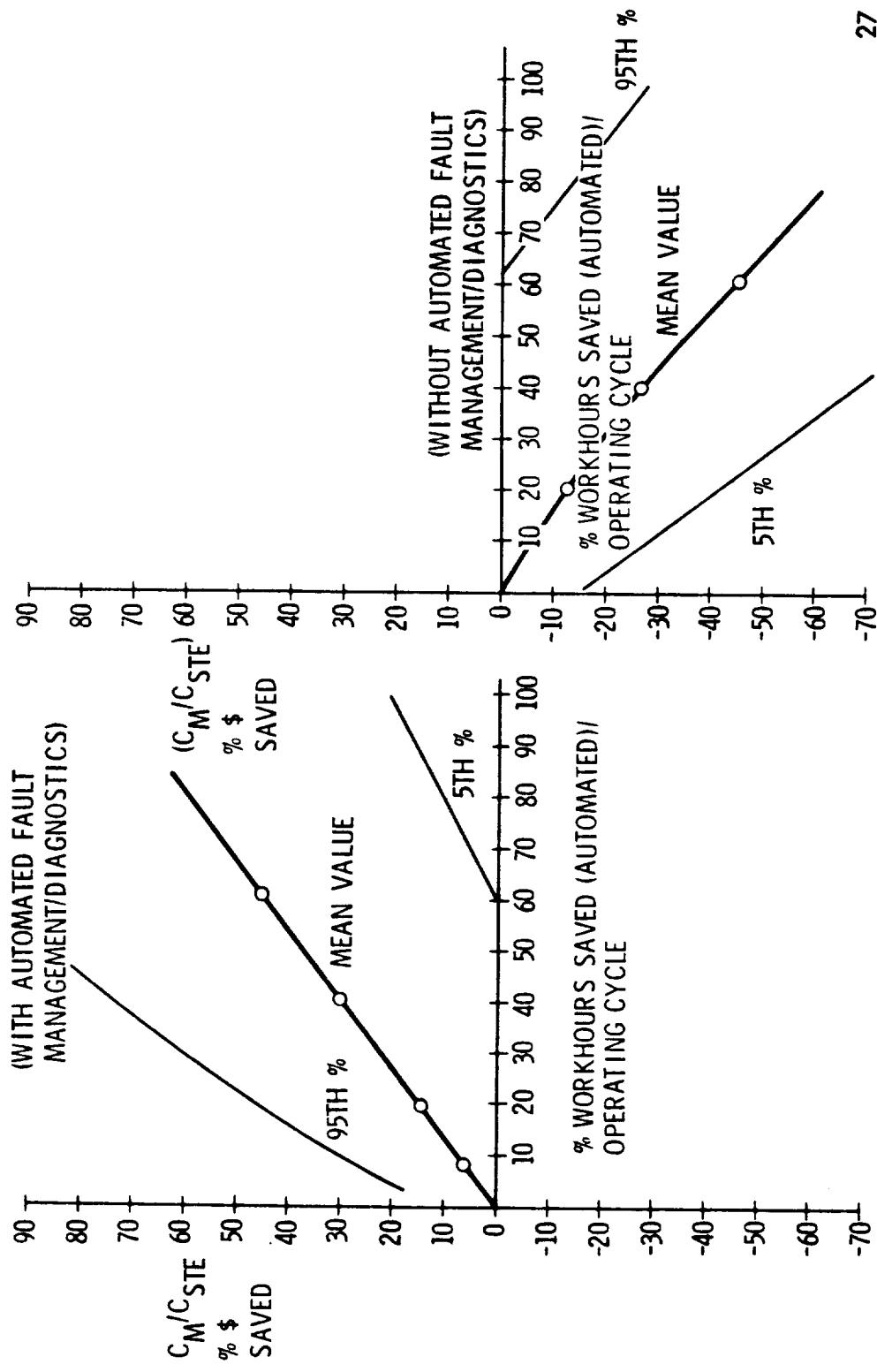
- USE LARGE AUTOMATED SYSTEMS REQUIRING SIMILAR FUNCTIONS
 - MONITORING
 - VERIFICATION OF DATA
 - ASSEMBLY/CONTROL OPERATIONS
 - PLANNING
 - FAULT ISOLATION/MANAGEMENT
- USE LARGE AUTOMATED SYSTEMS WITH LONG-LIFE CYCLES IN WHICH OPERATIONS BECOME REPETITIVE
- USE LARGE AUTOMATED SYSTEMS WITH SIMILAR COMPLEXITIES

- NAVY F/A - 18 AUTOMATED AIRCRAFT CONTROL/FAULT MANAGEMENT
- BOEING CO. COMMERCIAL AIRLINE AUTOMATION
- GENERAL MOTORS AUTOMATED FACTORY OF THE FUTURE
 - AUTOMATED AUTOMOBILE ASSEMBLY LINE EXPERIENCE
 - AUTOMATED TRANSMISSION ASSEMBLY LINE EXPERIENCE
- EPRI: AUTOMATED MAINTENANCE IN NUCLEAR POWERPLANTS
- SANDIA: AUTOMATED INSTALLATION METHODS FOR PHOTOVOLTAIC ARRAYS
- SRI: AI/ROBOTICS APPLICATIONS TO NAVY AIRCRAFT MAINTENANCE
- JPL: AUTOMATED UNDERGROUND MINING SYSTEMS

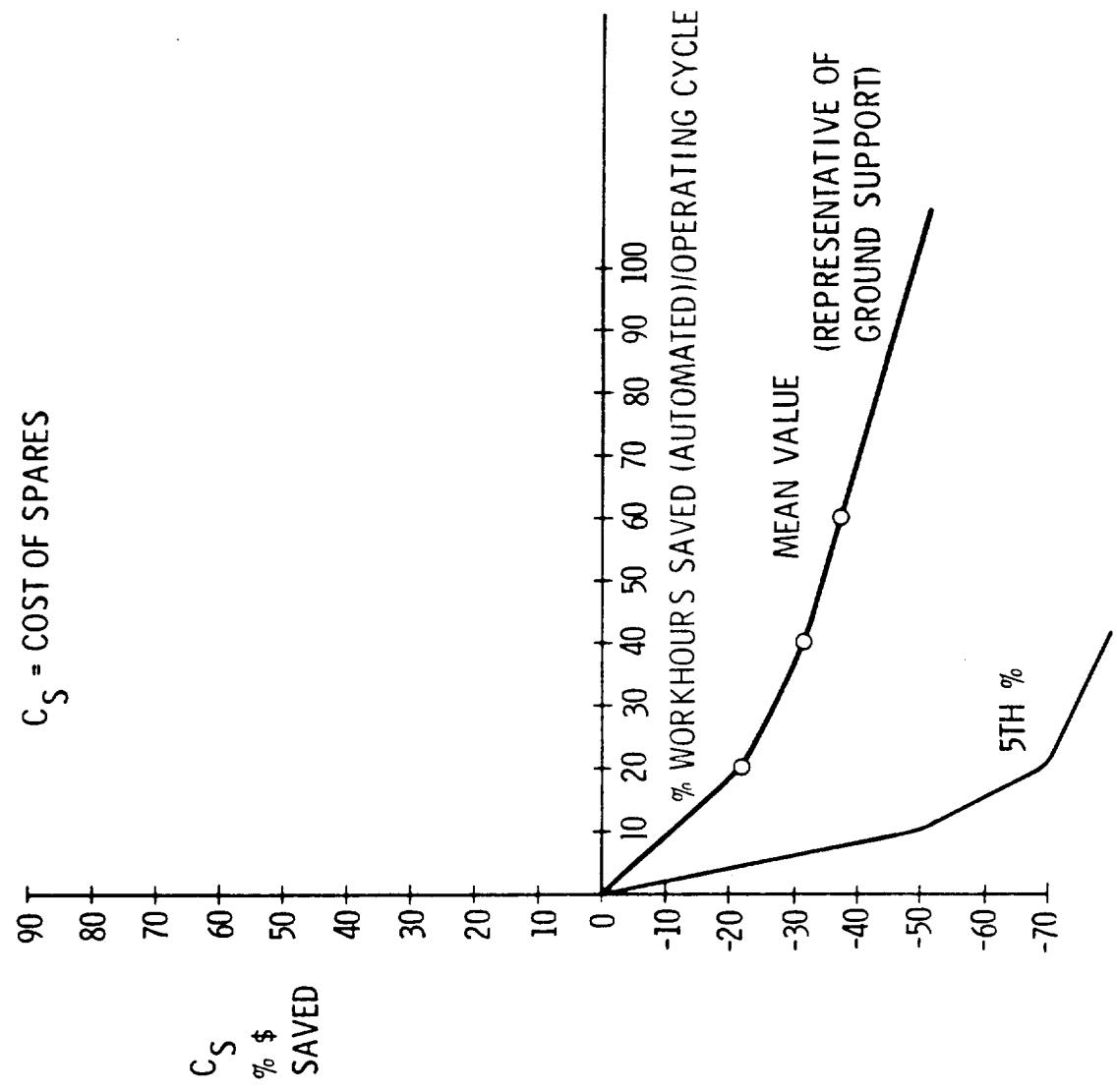
C_{MP} = COST OF WORKFORCE

JPL

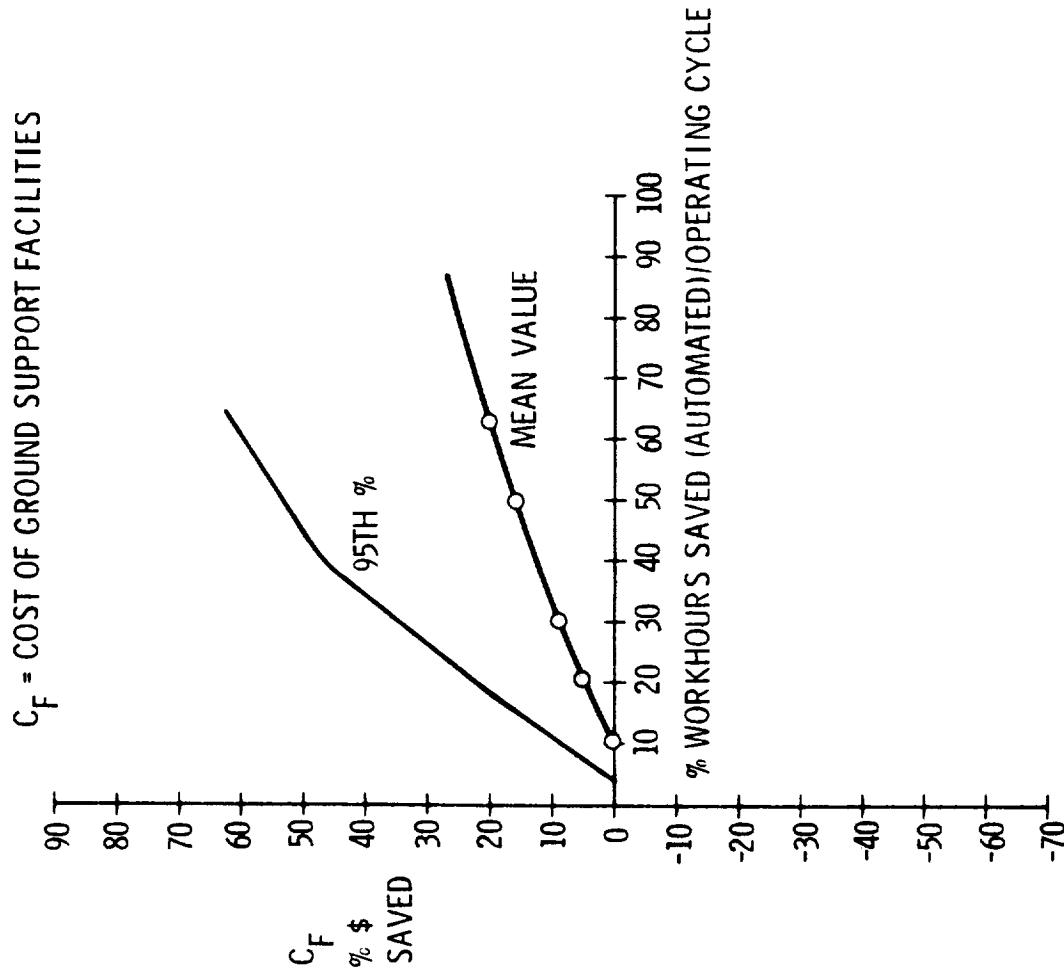
C_M = COST OF MAINTENANCE
 C_{STE} = COST OF SUPPORT AND TEST EQUIPMENT



JPL

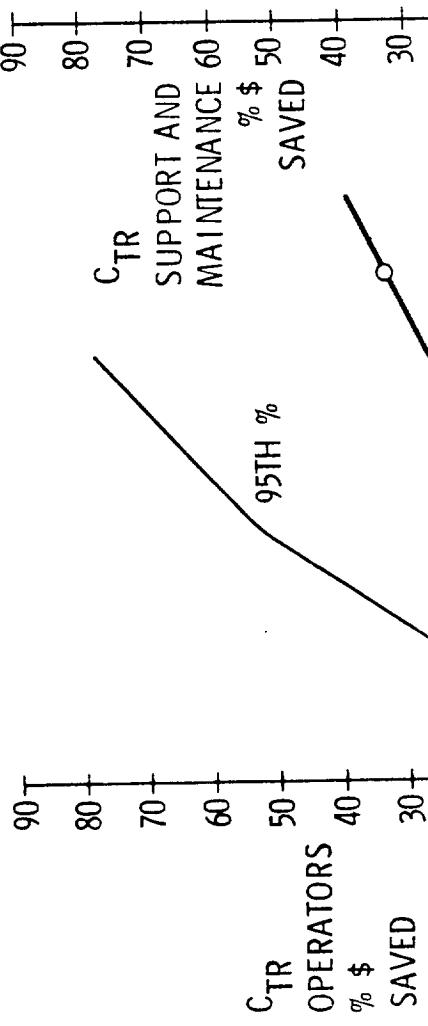


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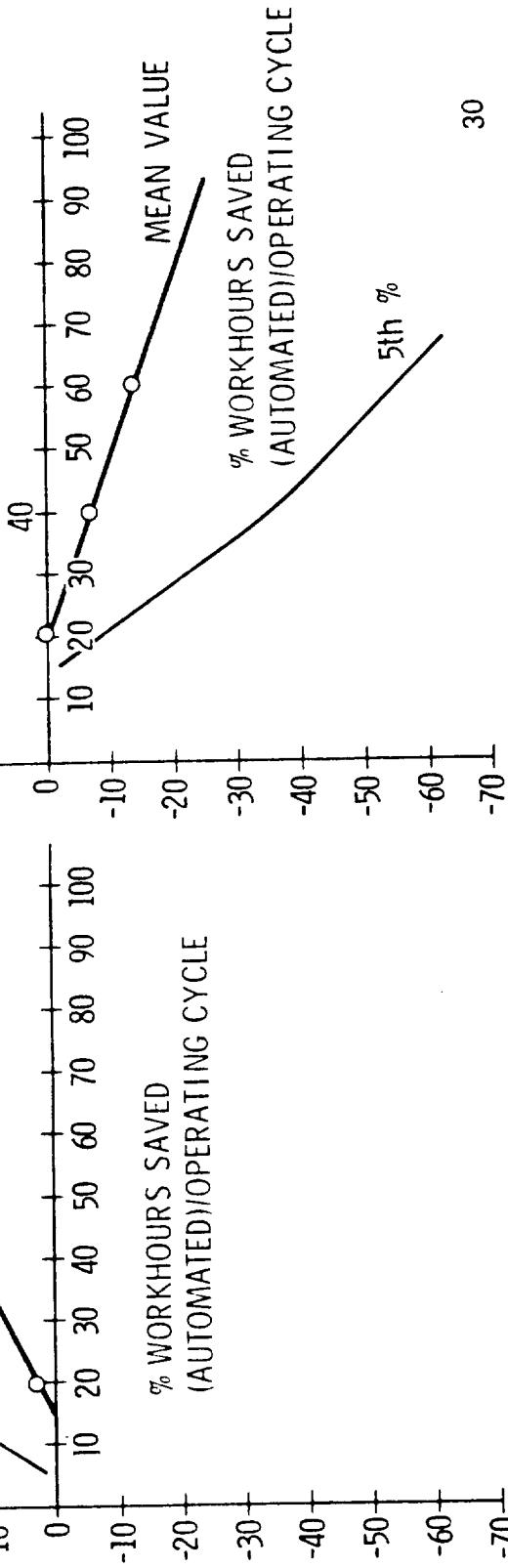


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C_{TR} = COST OF TRAINING



1091



30

One last important aspect of the IOC/life cycle cost impacts of automation is to consider the worth of any productivity improvements in on-orbit operations. In this study it is assumed that on-orbit workforce will not be reduced; rather, NASA may benefit from the sharing of station costs (with the government/private sector) by allowing additional on-orbit time for extra payloads. It is understood that this area requires considerable attention and investigation. For this study the viewer will see how some representative numbers were selected to demonstrate the potential impact of the value of on-orbit savings on reducing automation costs. The lower end of the cost range reflects the possibility that, by evolving toward a more reliable Shuttle (i.e., being able to increase the frequency of launches), some of the large fixed launch costs can be reduced. The upper end of the cost spectrum reflects a more standard costing approach that combines all yearly fixed and recurring (e.g., maintenance, supplies, logistics support, etc.) costs. Without having a NASA published figure at this time, it was decided to use a mean value cost and revenue figure for demonstration purposes.

VALUE OF CREW PRODUCTIVITY ON-ORBIT

- FOUNDATION FOR PROJECTIONS
 - BOEING
 - ROCKWELL INTERNATIONAL
 - LOGSDON, J., "U.S. INITIATIVES IN SPACE COMMERCIALIZATION",
GWU, WASHINGTON D.C.
 - MICROGRAVITY RESEARCH ASSOCIATES
 - WORKHOUR VALUE (1985\$)
 - PRIVATE SECTOR
 - COST/WORKHOUR = \$4,000 TO \$15,000 (MEAN VALUE OF \$9,500)
 - REVENUE/WORKHOUR = \$11,000 TO \$18,000 (MEAN VALUE OF \$14,500)
 - NET VALUE/WORKHOUR = \$5,000 (OF WHICH NASA MAY CHARGE A
PERCENTAGE TO RECOUP EXPENSES)
 - GOVERNMENT SECTOR
 - NET VALUE WILL BE MEASURED IN "ADDITIONAL PAYLOADS" THAT CAN BE
FUNDED BASED ON ADDITIONAL MANHOURS AVAILABLE FOR TENDING/
OPERATING PAYLOADS

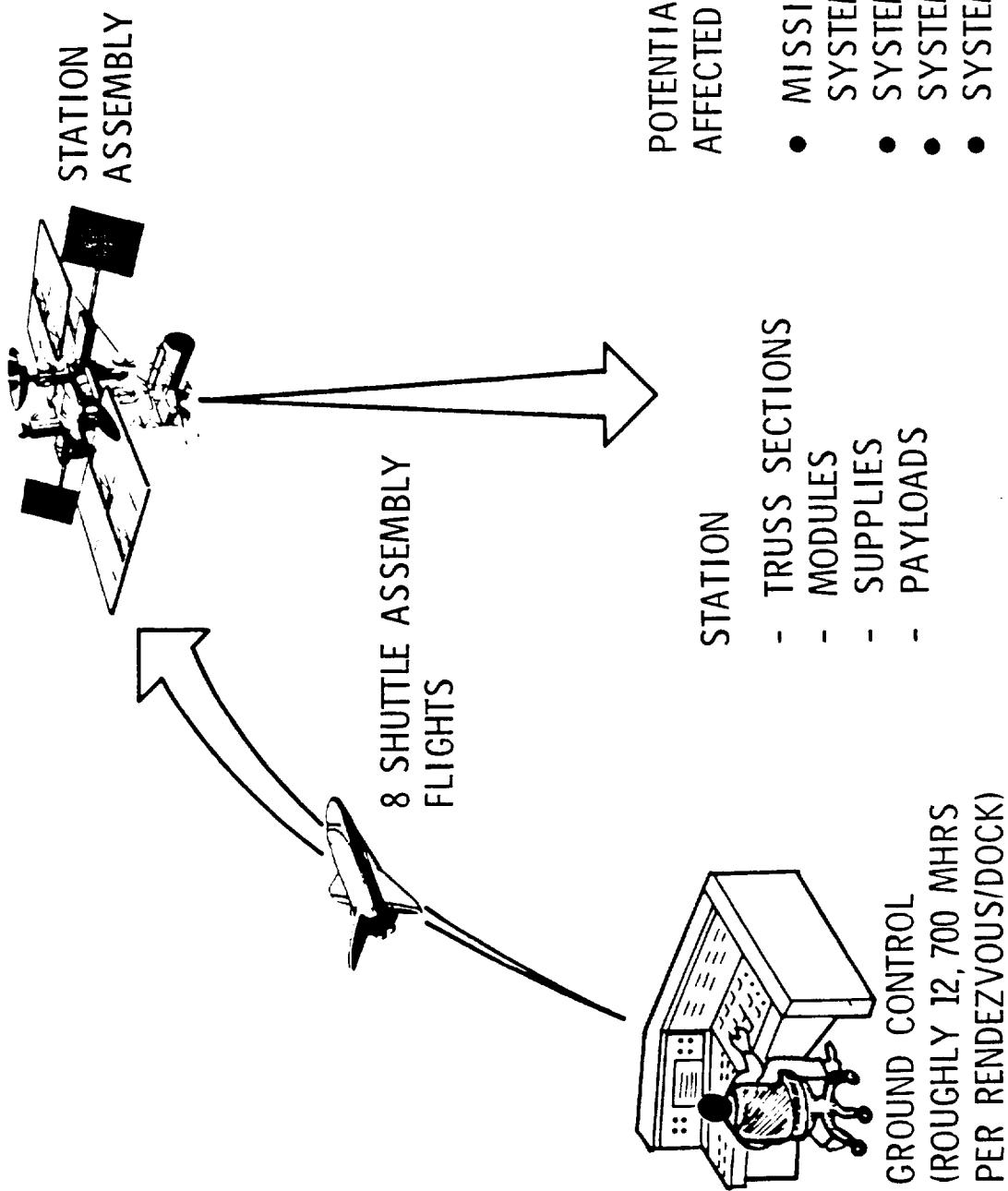
Once all the potential costs and savings have been tabulated for the complete array of human-machine alternatives, the best alternatives are selected for each subsystem by picking those exhibiting a positive cost savings (i.e., having the potential of lowering the IOC/life cycle subsystem baseline cost) and reduction in exposure to hazards. To demonstrate the technique, it was decided to develop some potential IOC and growth scenarios that exercised the rendezvous/docking function. The two scenarios picked were: (1) automated Shuttle-Station rendezvous/docks for the IOC assembly operations, and (2) automated rendezvous/docks of the Shuttle/OMV-Station during satellite servicing operations. The viewer should not be too concerned with the application of the automation conceptual design to both Shuttle and Station/OMV control. In developing the automation concept, the design team addressed the complete range of rendezvous/docking problems; therefore, the design applies equally to all systems. Additionally, although there may be differences in some hardware, the major driving cost is software. Therefore, the design is not terribly sensitive to hardware integration costs.

Once the scenarios were developed, the automation cost tradeoffs could be completed. For IOC the best human-machine alternatives (those offering substantial productivity improvements with the least cost) are those that fall short of total automation of ground operations. The viewer should remember the Shuttle IOC viewgraph displays the best of all possible human-machine alternatives. Similarly, the growth scenario depicts automation of all ground operations with ground teleoperation (essentially the human-tended design) as offering the best (cost reduction and safety) payoff. In fact, a more parametric approach can be taken such as: (1) no reduction in on-orbit workforce, or (2) employment of other human-machine combinations. When this is accomplished the viewer will see a performance envelope develop which identifies a picture of the complete cost/automation payoffs.

- CONVERT CREW PRODUCTIVITY IMPROVEMENTS FOR EACH ALTERNATIVE INTO:
 - DOLLAR SAVINGS TO NASA
 - COMBINE PRODUCTIVITY DOLLAR VALUES WITH NET COSTS/BENEFITS FROM AUTOMATION
 - ESTABLISH CREW HOURS EXPOSED TO HAZARDS (E.G., DURING CREW INTERFACE WITH FUNCTION) FOR EACH ALTERNATIVE
 - BEST HUMAN-MACHINE ALTERNATIVES FOR IOC AND OUT-YEARS
 - MUST EXHIBIT POSITIVE COST SAVINGS
 - MINIMIZE EXPOSURE TO HAZARDS

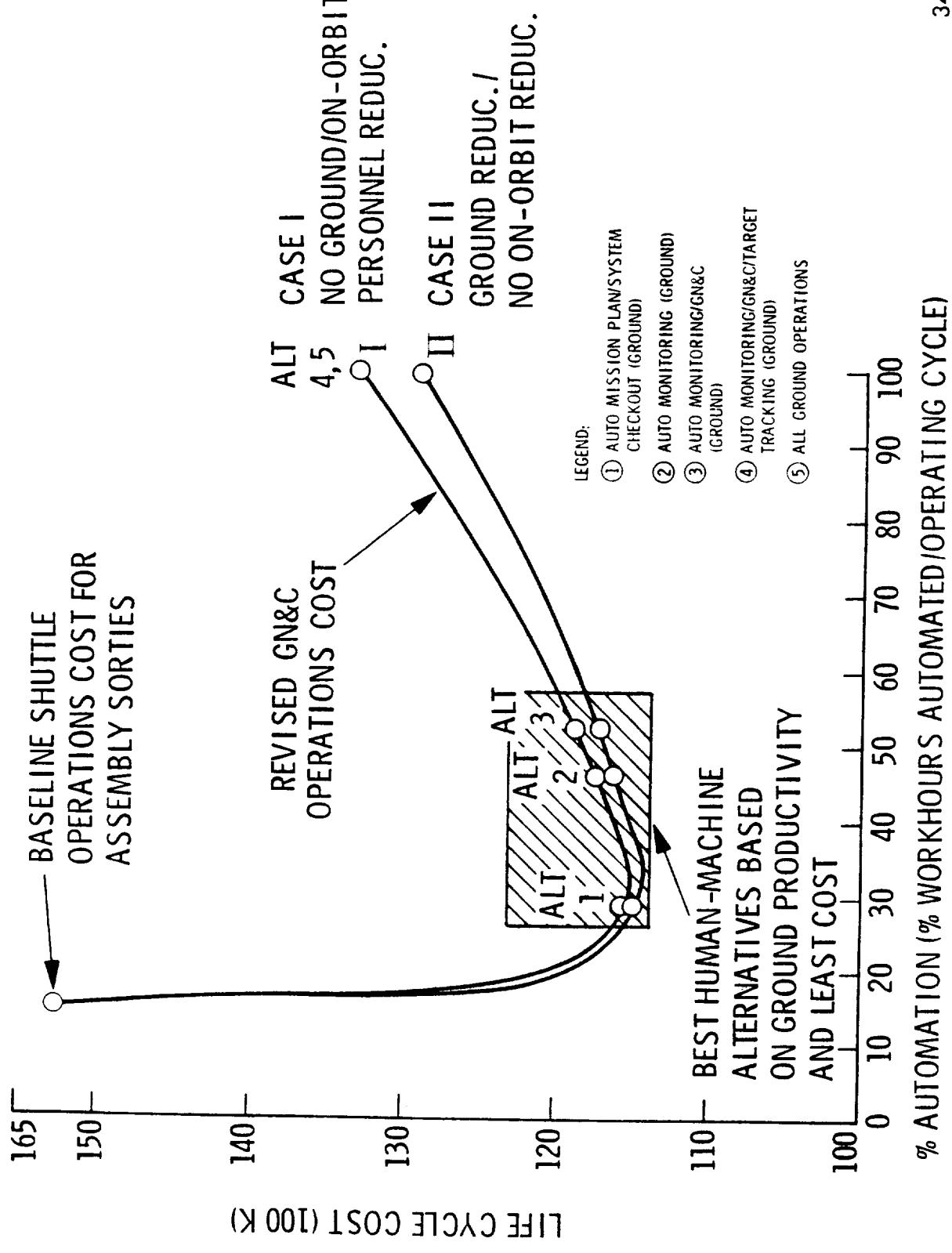
JPL

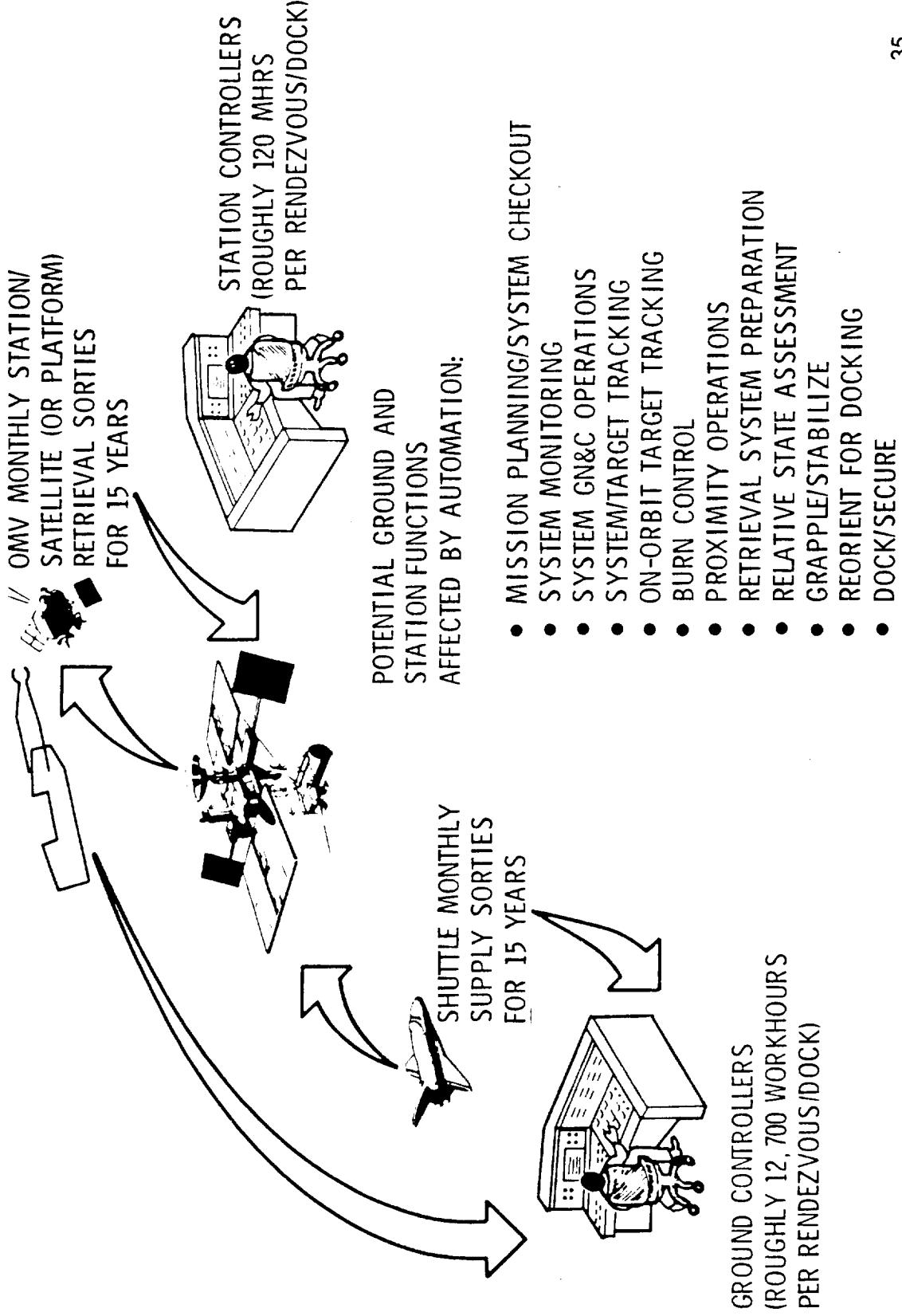
IOC MISSION SCENARIO



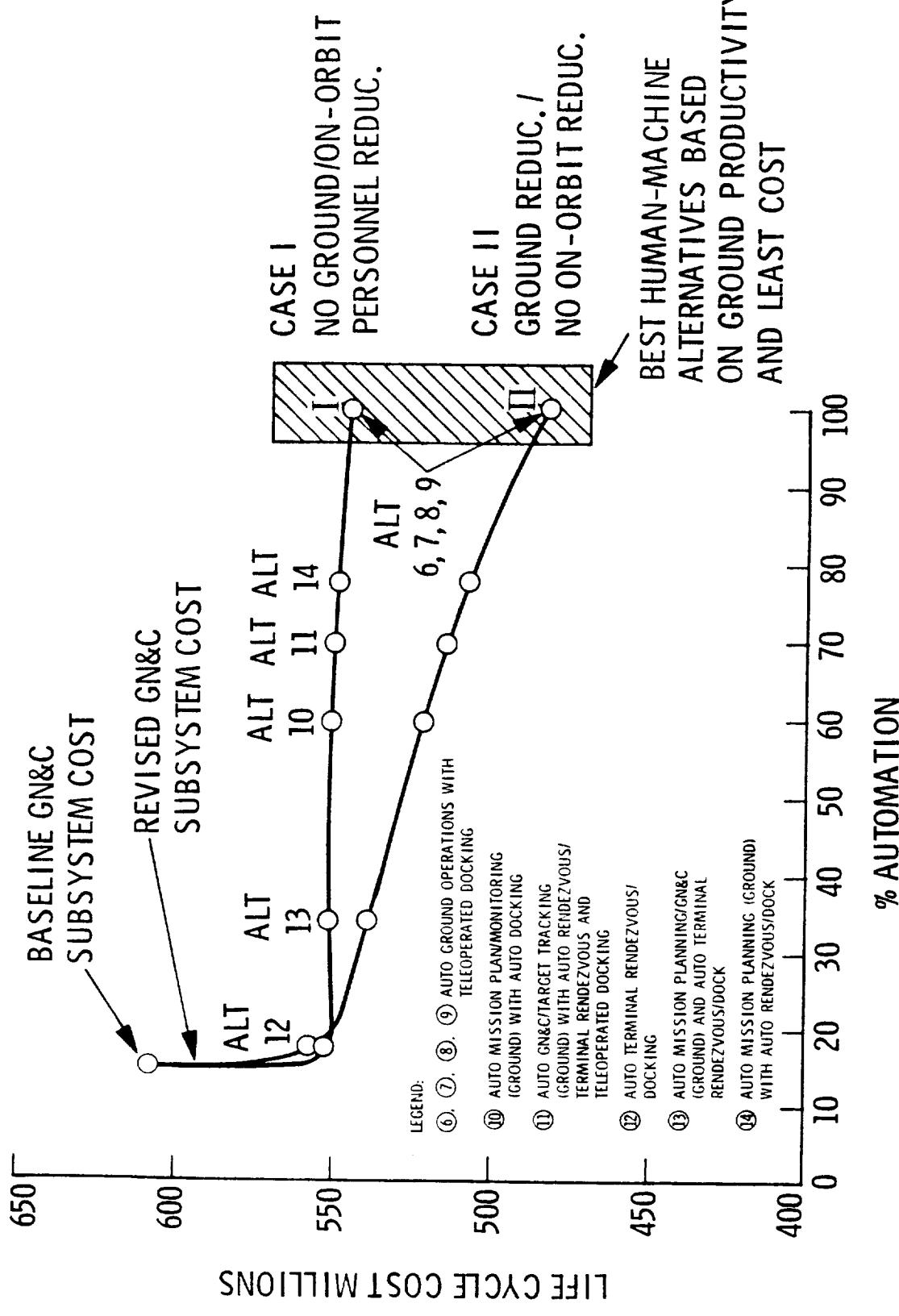
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LIFE-CYCLE COST VS. PERCENT AUTOMATION
SHUTTLE IOC PHASE



STATION/OMV GROWTH MISSION SCENARIO

SPACE STATION/OMV OPERATION PHASE
LIFE-CYCLE COST VS. PERCENT AUTOMATION

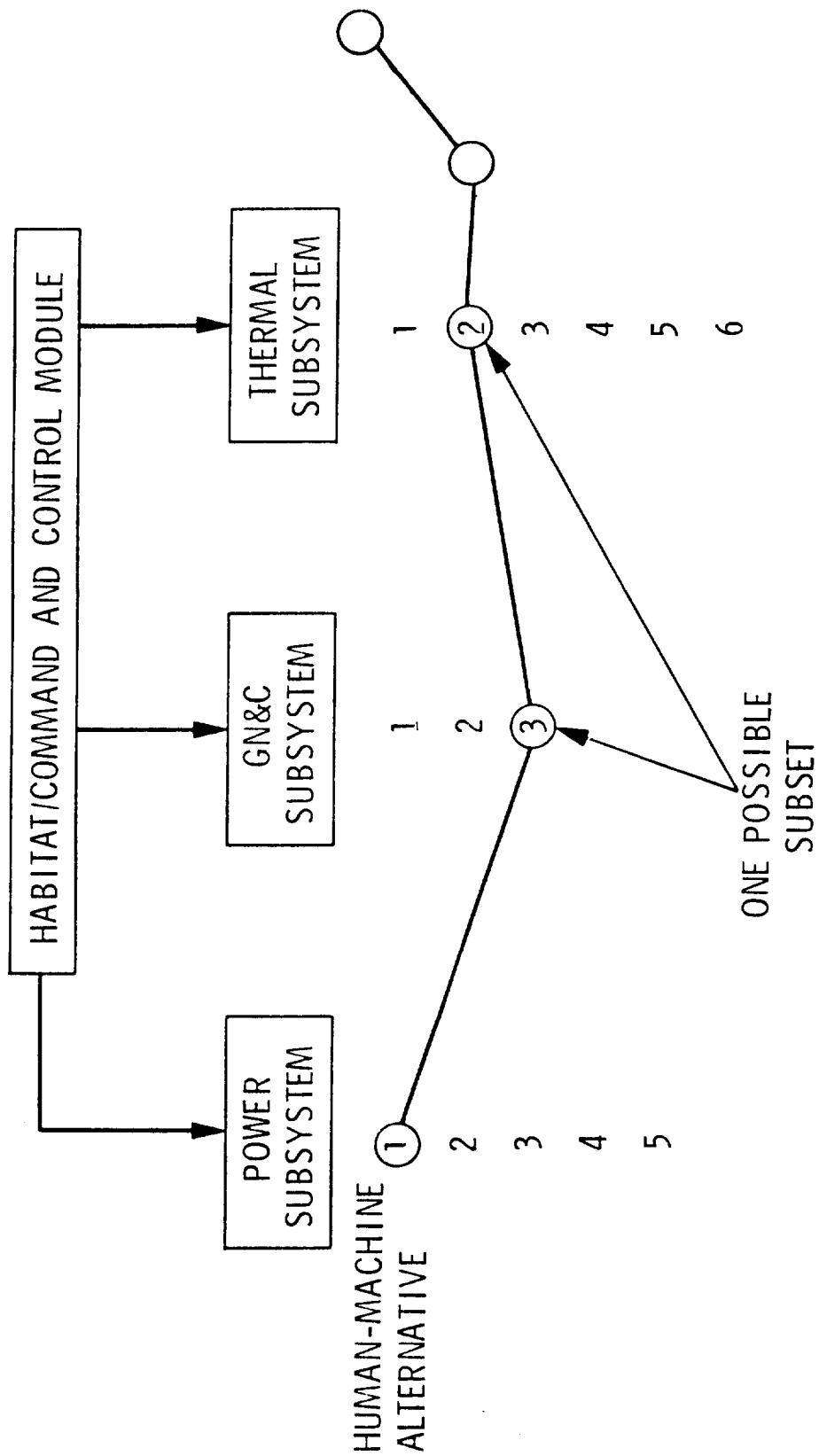


Once the best alternatives are picked for each subsystem, the optimization process must be expanded to consider the larger system level constraints. This is important because: (1) once subsystems are considered in total, there respective component integrations (i.e., sharing of cost) may impact the selection of more costly human-machine alternatives; and (2) other system level constraints such as budget, weight, power, and overall crew safety may further impact the final selection of the best human-machine mix. The viewer should be aware that one of the major strengths of this methodology is that it optimizes around a budget constraint that can be imposed as a single target or on a year-by-year basis. Clearly, because the technique has not been applied to all subsystems, the system optimization step can not be demonstrated. However, the optimization model considers standard techniques such as linear programming (i.e., the solution of a set of simultaneous equations formed by an array of subsystem human-machine alternatives and the system level constraints), or the branch and bound option limiting technique.

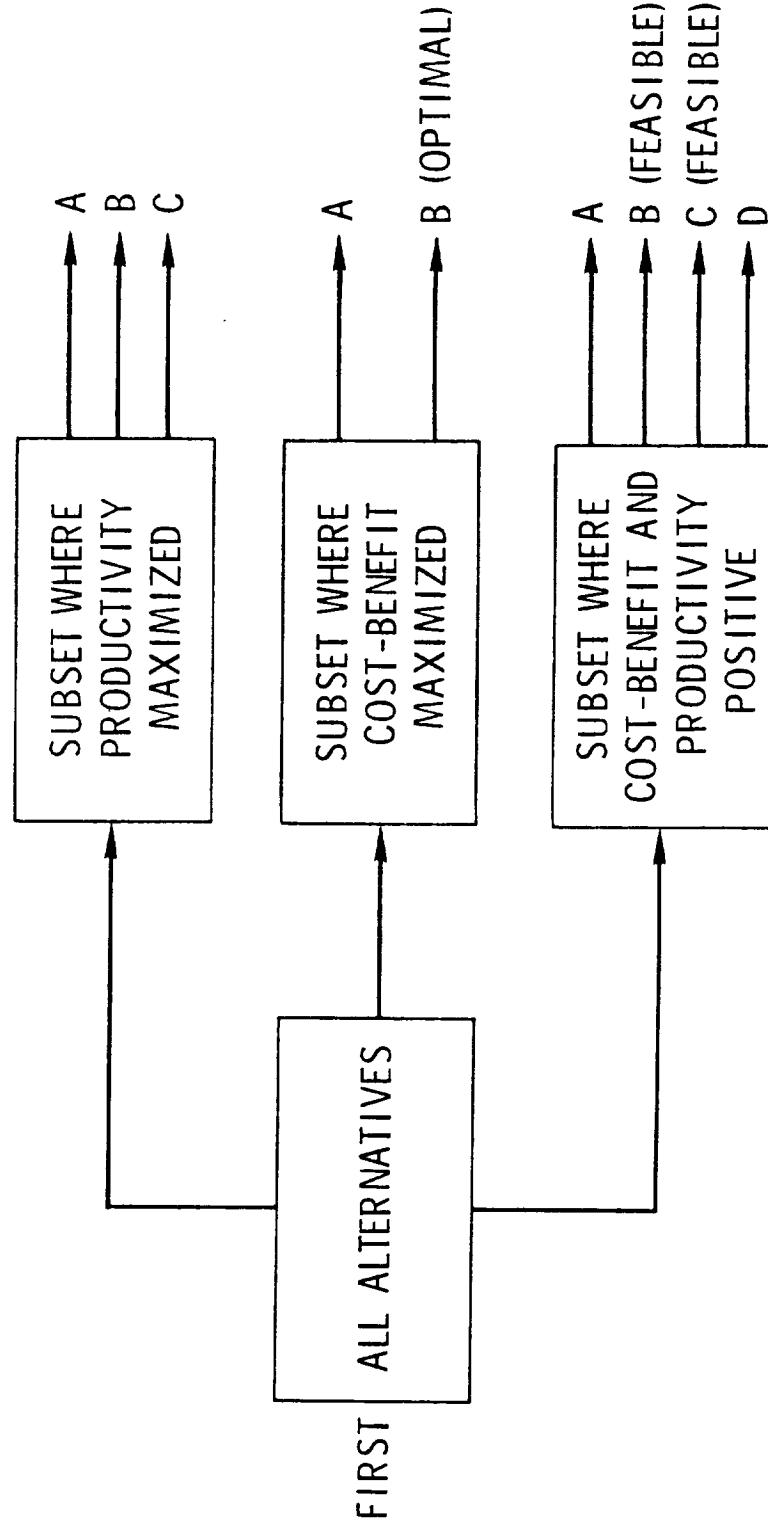
OPTIMIZE HUMAN-MACHINE MIX FOR TOTAL SYSTEM

- ESTABLISH BEST HUMAN-MACHINE ALTERNATIVES FOR ALL SUBSYSTEMS/ MODULES IN SPACE STATION
- CALCULATE CHANGE IN SUBSYSTEM COST, WEIGHT, AND POWER USAGE CONSIDERING SUBSYSTEM INTEGRATION/SHARED COSTS
- APPLY TRIAL AND ERROR OPTIMIZATION TECHNIQUES
 - LINEAR PROGRAMMING
 - BRANCH AND BOUND METHOD
- PICK OPTIMAL SUBSET OF ALTERNATIVES FOR ALL MODULES SUBJECT TO A SYSTEM:
 - COST TARGET (IOC AND ANNUAL CEILINGS)
 - WEIGHT CONSTRAINT
 - POWER CONSUMPTION CONSTRAINT
 - SAFETY CONSTRAINT (HOURS EXPOSED/MISSION DAY)

DEFINITION OF A "SUBSET" OF HUMAN-MACHINE ALTERNATIVES



- BRANCH AND BOUND SOLUTION FRAMEWORK

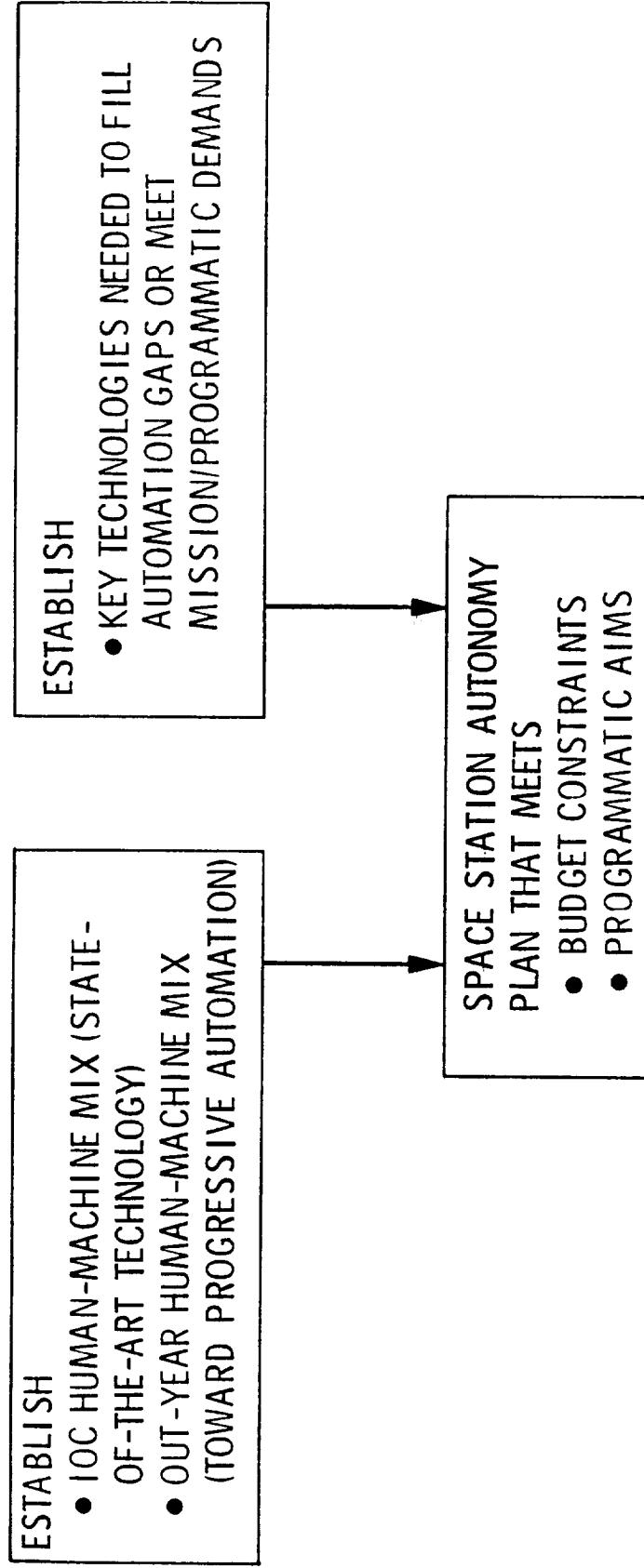


As stated earlier, the conceptual design is basically constructed of state-of-the-art technologies (i.e., technologies that will be available by IOC). However, as demonstrated with the automated GN&C example, automation may require advanced technologies. Therefore, the system level optimization process must also address the best technology incorporation path to follow. To perform this step in the methodology, the productivity, cost, and safety design variables had to be expanded into a larger array of technology variables, such as, technology reliability, importance to station growth, R&D risk, and ease of incorporation. The technique used to assess these more encompassing variables (called attributes) is termed multi-attribute decision analysis (MADA). Very simply, MADA takes the ranges of cost, productivity, reliability, etc., for each potential technology, and after reviewing the ranges with a group of technology experts, establishes the relative importance of each attribute and technology toward meeting mission/programmatic goals. Once the relative technology weights are established, the technologies can be ranked from most, to least desirable. The best technologies might be those that satisfy mission goals at the least cost and best reliability; with the least desirable being those that are very costly, risky in terms of when they might be available, and low payoff in terms of meeting mission goals. After the ranking is completed, the combined optimal human-machine mix and technology incorporation plot provide a well founded station IOC and growth automation/autonomy plan.

RANK ORDER ASSOCIATED ADVANCED AUTOMATION TECHNOLOGIES

- ESTABLISH LIST OF ADVANCED TECHNOLOGIES
 - ATAC REPORT
 - LEVEL B TECHNOLOGY PLANNING STUDY
- ESTABLISH MEASURES FOR RANKING TECHNOLOGIES
 - COST (IOC/LIFE CYCLE)
 - CREW PRODUCTIVITY ENHANCEMENT
 - ADDITIONAL WEIGHT/POWER REDUCTIONS/INCREASES
 - ADDITIONAL SAFETY
 - RELIABILITY IMPROVEMENTS/DEGRADATION
 - TECHNOLOGY IMPORTANCE (TO OUT-YEAR MISSIONS)
 - R&D TIME
 - RETROFIT AMENABILITY (EASE OF INCORPORATION)
- APPLY MULTI-ATTRIBUTE DECISION ANALYSIS (MADA) TO RANK ORDER TECHNOLOGY OPTIONS

- MADA IS USED PRIMARILY ON COMPLEX SYSTEMS
- MADA IS EFFECTIVE WHEN MAKING SYSTEM LEVEL DECISIONS INVOLVING SEVERAL OBJECTIVES, OR ATTRIBUTES
- MADA STRUCTURE:
 - DEFINES OBJECTIVES
 - ESTABLISHES MEASURES OF OBJECTIVES (CAN BE QUANTITATIVE OR QUALITATIVE)
 - SELECTS GROUP OF EXPERTS, KNOWLEDGEABLE IN BOTH TECHNOLOGIES AND OBJECTIVES
 - REVIEWS RANGE OF OBJECTIVE STATES (HIGH COST VS. LOW COST) WITH EXPERTS AND IDENTIFYS STATES OF GREATEST UTILITY FOR EACH SYSTEM OPTION
 - SELECTS OPTIONS THAT MAXIMIZE UTILITY ACROSS ALL ATTRIBUTES



As shown in the preceding viewgraphs, when weighing the liabilities and benefits of automation, consideration will need to be given to advanced automation technologies. To incorporate this crucial aspect of the human-machine tradeoff problem in the overall modeling scheme, a technology forecasting study was conducted. This study drew strongly on the results of the contractor/SRI ATAC related technology studies, some DARPA research in autonomous ground vehicles, and in-house technology expertise. This system-oriented technology study considered: (1) all station subsystems, (2) relative functional/subsystem complexities, (3) potential space qualification delays, and (4) subsystem integration complexities. Although largely applicable to the tradeoff problem, this research provided other useful spinoffs. First, the forecasting study provided a strong foundation for making ad hoc contributions to the design of the ATAC report to Congress. Second, the research contributed some technology selection/implementation guidelines to the present Level B and Level C Phase B program initiation activities. Last, recognizing a potential need to structure the workpackage technology development programs, the forecasting study provided the basis for developing a software package to assist Level B and Level C in organizing and costing the advanced automation technology development program. Example outputs of the forecasting effort are enclosed in the viewgraph package.

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**TASK ELEMENT 3
SUPPORT TO ATAC/LEVEL B SE&I**

- PURPOSE
 - REVIEW AND ASSESS CONTRACTOR RESULTS FOR CALSPACE STUDY FROM SYSTEM LEVEL VIEWPOINT
 - PROVIDE INPUT TO ATAC REPORT (SUPPORT TO ERICKSON)
 - PROVIDE FORECASTING/PLANNING STRUCTURE INPUTS TO LEVEL B TECHNOLOGY IMPLEMENTATION PLAN
 - TECHNICAL STATUS
 - ATAC SUPPORT
- REVISIONS TO ATAC REPORT OUTLINE COMPLETED IN EARLY NOVEMBER 1984
 - SYSTEM LEVEL ISSUES IDENTIFIED END OF NOVEMBER 1984
 - KEY MAN/MACHINE TRADE ISSUES IDENTIFIED END OF NOVEMBER 1984
- REVIEW OF ATAC DRAFTS COMPLETED END OF JANUARY AND FEBRUARY 1985
 - REVIEW/REVISONS OF MANUAL FOR PRELIMINARY DESIGN OF SPACE STATION MACHINE INTELLIGENCE, ROBOTICS AND AUTOMATION, COMPLETED MARCH 1985
 - REVIEW/REVISION OF SPACE STATION AUGMENTATIONS FOR ADVANCED AUTOMATION AND ROBOTICS, COMPLETED APRIL 1985

TASK ELEMENT 3 (CONT'D)

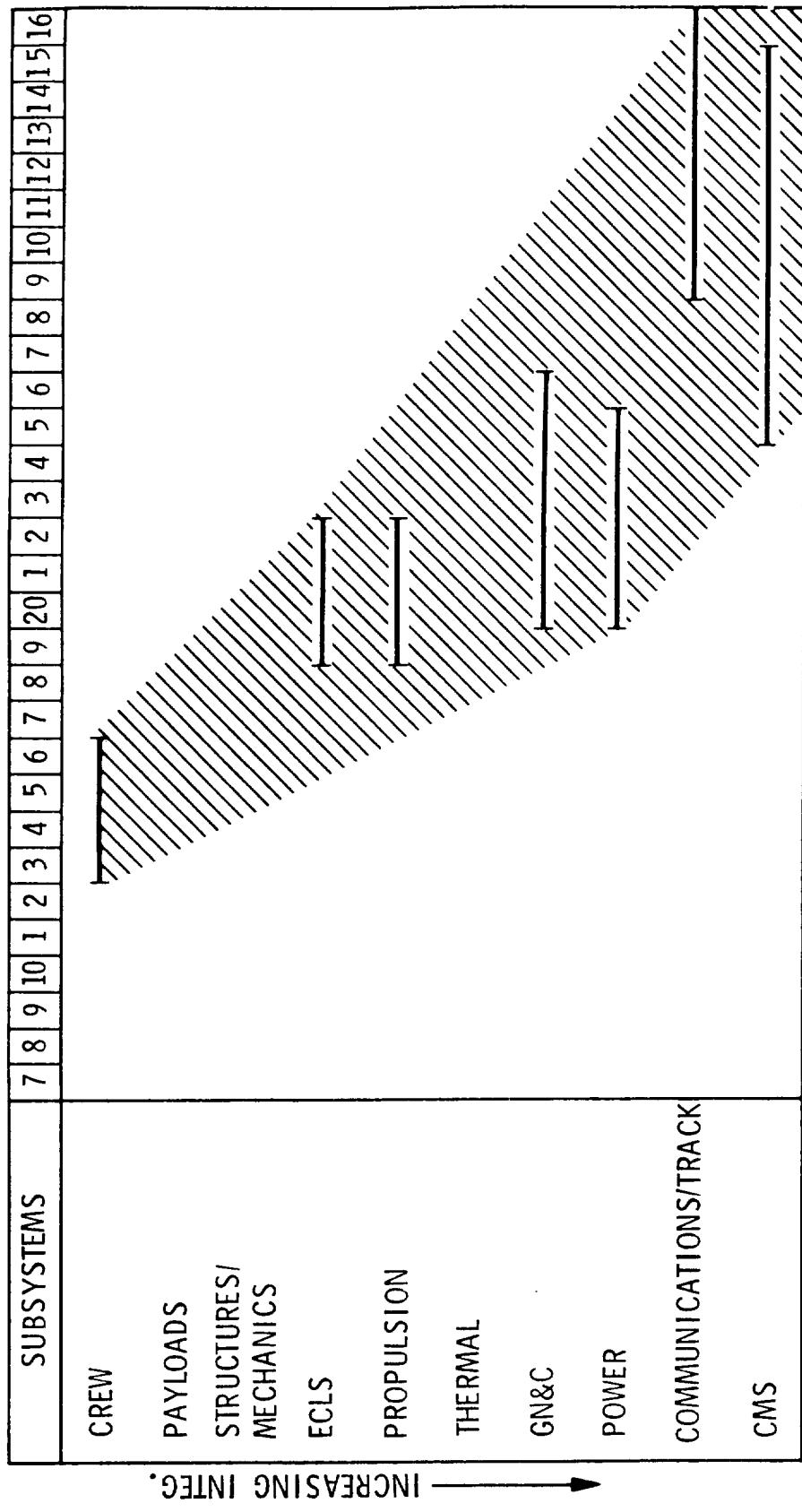
- TECHNICAL STATUS (CONT'D)
 - LEVEL B TECHNOLOGY IMPLEMENTATION PLAN INPUTS
 - AD HOC TECHNICAL SUPPORT TO DETAILEE BY REQUEST (ON-GOING)
 - REVIEW OF CONTRACTOR/SRI TECHNOLOGY FORECASTS COMPLETED END OF JANUARY 1985
 - MORE DETAILED AUTOMATION TECHNOLOGY AND FORECASTS DEVELOPED BY IN-HOUSE TECHNOLOGY SPECIALISTS
 - TECHNOLOGY FORECASTS/IMPLEMENTATION PLANNING STRUCTURE DEVELOPED CONSIDERING:
 - SUBSYSTEM FUNCTION DEFINITION
 - SUBSYSTEM INTEGRATION
 - SPACE QUALIFICATION
 - SUBSYSTEM COMPLEXITY

TASK ELEMENT 3 (CONT'D)

- TECHNICAL STATUS (CONT'D)
- LEVEL B (AND LEVEL C) IMPLEMENTATION PLANNING STRUCTURE CONTAINS:
 - EXPANDED TECHNOLOGY FORECASTING FOUNDATION
 - TECHNOLOGY DEVELOPMENT STEPS
 - SPACE QUALIFICATION IMPACT
 - SUBSYSTEM INTEGRATION IMPACTS
 - SUBSYSTEM COMPLEXITY IMPACTS
 - ADDITIONAL DECISION VARIABLES SUCH AS AUTOMATION COSTS/BENEFITS, TECHNOLOGY RELIABILITY/LIMITATIONS, TECHNOLOGY RISK, AND IMPORTANCE TO GROWTH (MISSIONS)
 - METHOD FOR SELECTING IOC TECHNOLOGIES
 - SPACE STATION FORECASTING/RESOURCE ASSESSMENT SOFTWARE TOOL

EFFECT OF FUNCTIONAL COMPLEXITY/INTEGRATION ON
TECHNOLOGY AVAILABILITY

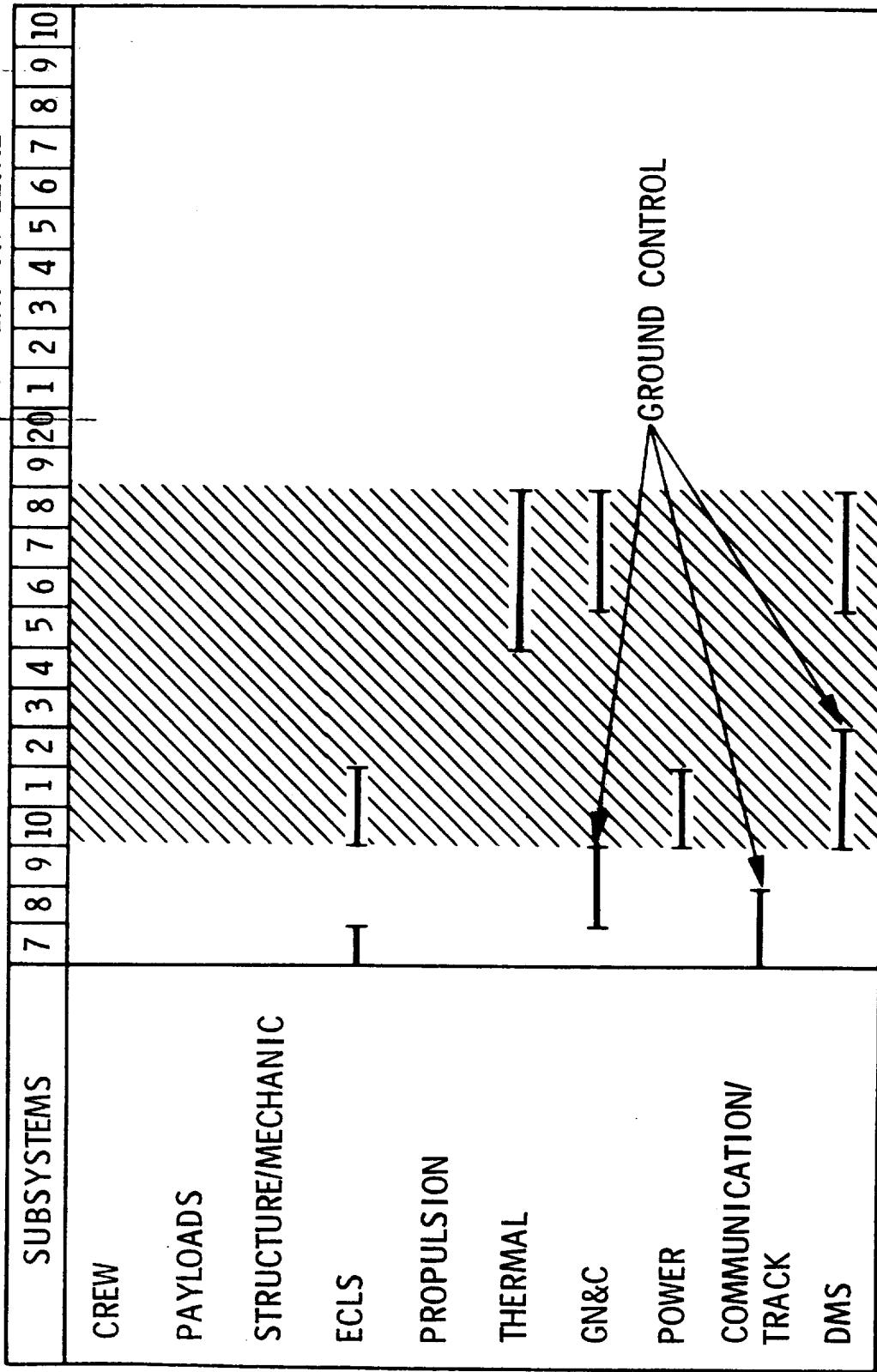
TECHNOLOGY AREA: EXPERT SYSTEM FAULT MANAGEMENT TIMELINE



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EFFECT OF FUNCTIONAL COMPLEXITY/INTEGRATION
ON TECHNOLOGY AVAILABILITY

TECHNOLOGY AREA: RULE BASED DIAGNOSTIC/FAULT MANAGEMENT TIMELINE



FEASIBLE IOC AUTOMATION RELATED TECHNOLOGIES

TECHNOLOGY AREA	SUBSYSTEM	IOC AUTOMATION RELATED TECHNOLOGIES																
		OPs	MODELLED	AUTOMATED / PLANSCHED.	SIMPLIFIED EXPERT SYSTEMS	EXPERT CONTROL	SENSORS	FUSION	ADAPTIVE MANAGEMENT	Voice CONTROL	DATA STORAGE	ARCHIVALS	BASED DIGI./ AUTO. RULE	FAULT MGT.	EXPERT MGT.	FAULT MGT.	0	
CREW		X	X	X	0													
PAYLOADS		X	0	X														
STRUCTURE/MECHANICS		X	(10-15M)															
ECLS		X	X	0	0													
PROPELLION		X	(LIMITED)	X														
THERMAL		X	X															
GN&C		X	(LIMITED)	X														
POWER		X	X															
COMMUNICATION/TRACK		X	X															
DMS		X	X															

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SPACE STATION AUTOMATION TECH
GN&C
Operations & Services

Activity: #13 RULE EASED FAULT DIAG(GRND)
CRITICAL

Early Start: 01/04/1983
Late Start : 01/04/1986

Resources Allocated:

Name	Duration (Days)	Amount used	Cost Basis	Cost to Complete
Total				\$0.00

Predecessors:

Activity:
2 GN&C MODEL BUILD

Successors:

Activity:
14 SIMPLE ON ORBIT RULE BASE DIAGONAL/01/1990

Date: 01/01/1986

Early Finish: 12/29/1989
Late Finish : 12/29/1989

EARLY FINISH 01/01/1983

SLACK START 01/01/1990

LATE FINISH 01/01/1983

AVAIL 0

In summary, the results of the FY 85 SE&I Autonomy Task (as shown in this presentation) contribute in several ways to the Phase B effort. First, and foremost, the dictated charter for this task is the development of analytical tools to support Level B and Level C in conducting the Phase B work package studies. This presentation clearly demonstrates several tools that will be useful to both Level B and Level C and also the workpackages. These tools are, respectively:

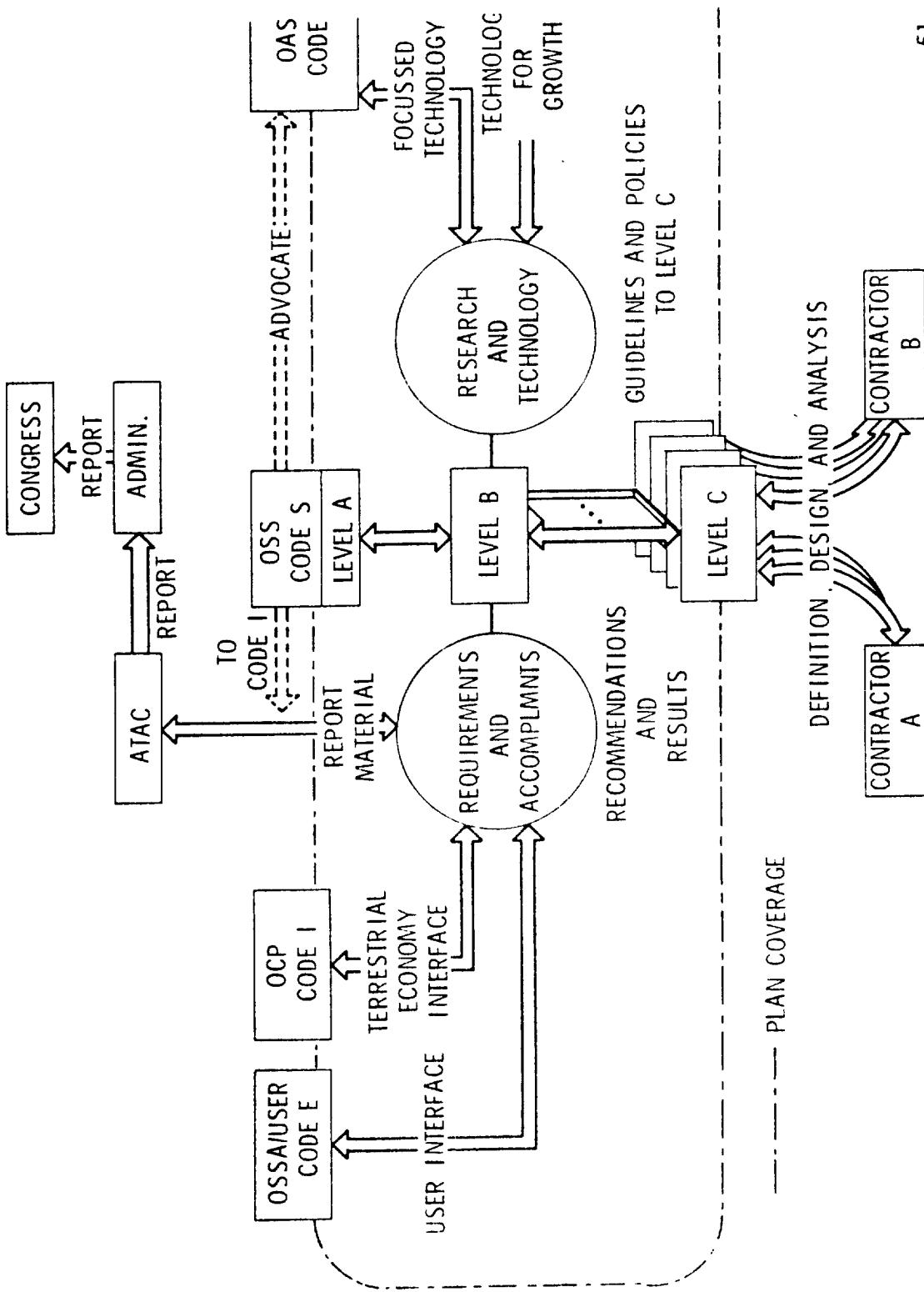
- (1) Automation functional analysis.
- (2) Conceptual design/costing of automation.
- (3) Automation tradeoff structures.
- (4) Automation cost tradeoffs (with supporting applications).
- (5) Technology forecasting/planning structures for all station subsystems (with a supporting planning and resource assessment package).

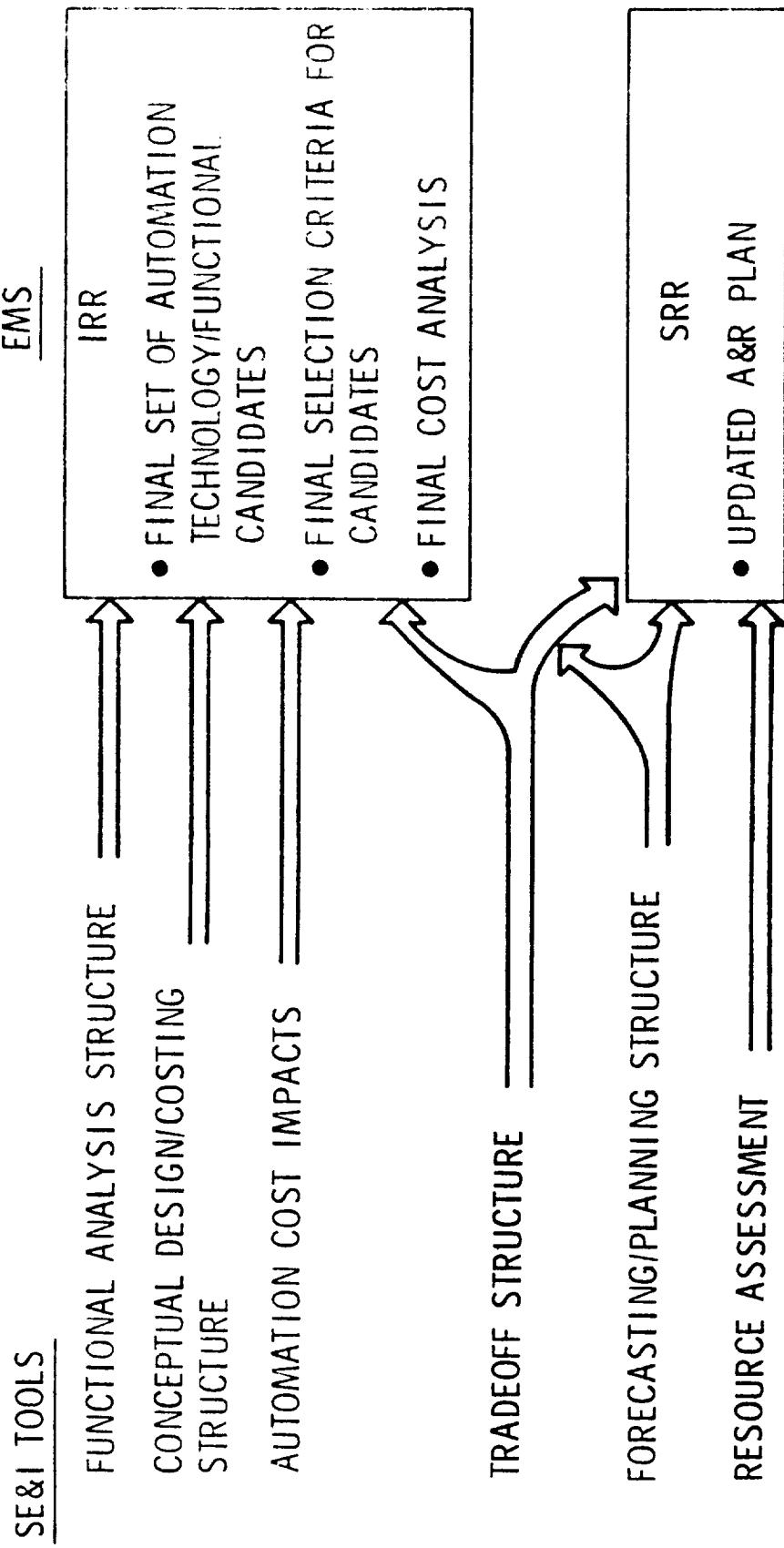
The last two viewgraphs in this presentation package take the above task outputs and show the viewer how these tools fit into the present Level B Technology Implementation Planning effort. As a followup to this presentation and the published methodology, three supporting white papers in the areas of: (1) GN&C automation tradeoffs, (2) approximation of the value of on-orbit workhours, and (3) technology implementation planning structure, are being published. These white papers will be available by summer FY 85.

SUMMARY

- PHASE B WORKPACKAGE SUPPORT
- HUMAN-MACHINE AUTOMATION TRADEOFF METHODOLOGY PROVIDES:
 - AUTOMATION DESIGN CONSIDERATIONS (AUTOMATION WILL NOT REPLACE ALL GROUND OR ON-ORBIT CREW FUNCTIONS)
 - FUNCTIONAL ANALYSIS STRUCTURE
 - CONCEPTUAL DESIGN AND COST STRUCTURE
 - TRADEOFF STRUCTURE
 - AUTOMATION COST IMPACTS (BOTH POSITIVE AND NEGATIVE)
 - EXAMPLE APPLICATIONS
- LEVEL B (LEVEL C) TECHNOLOGY FORECASTING/PLANNING STRUCTURE
 - PROVIDES IMPORTANT AUTOMATION TRADEOFF ELEMENT
 - GUIDES IOC TECHNOLOGY SELECTION
 - REINFORCES RESOURCE ASSESSMENT THROUGH SOFTWARE TOOL

OVERVIEW OF SPACE STATION AUTOMATION AND ROBOTICS MANAGEMENT PROCESS





SOME RECENT AND CURRENT WORK AT JPL IN FAULT TOLERANT COMPUTING

ELECTRONICS AND CONTROL DIVISION

SPACECRAFT DATA SYSTEMS SECTION

ADVANCED DATA SYSTEMS GROUP

DAVID J. EISENMAN

This presentation described a number of activities at JPL that are in various stages of development. These include: a self-checking computer module; an autonomous redundancy maintenance management subsystem; on-line self-test design techniques for VSLI & gate-array circuit technology; and an advanced general-purpose high-speed computer.

LIST OF ACTIVITIES TO BE REVIEWED

- SELF-CHECKING COMPUTER MODULE
- AUTONOMOUS REDUNDANCY MAINTENANCE MANAGEMENT SUBSYSTEM
- ON-LINE SELF-TEST DESIGN TECHNIQUES FOR VLSI & GATE-ARRAY CIRCUIT TECHNOLOGY
- ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER

SELF-CHECKING COMPUTER MODULE OVERVIEW
DESIGN GOALS

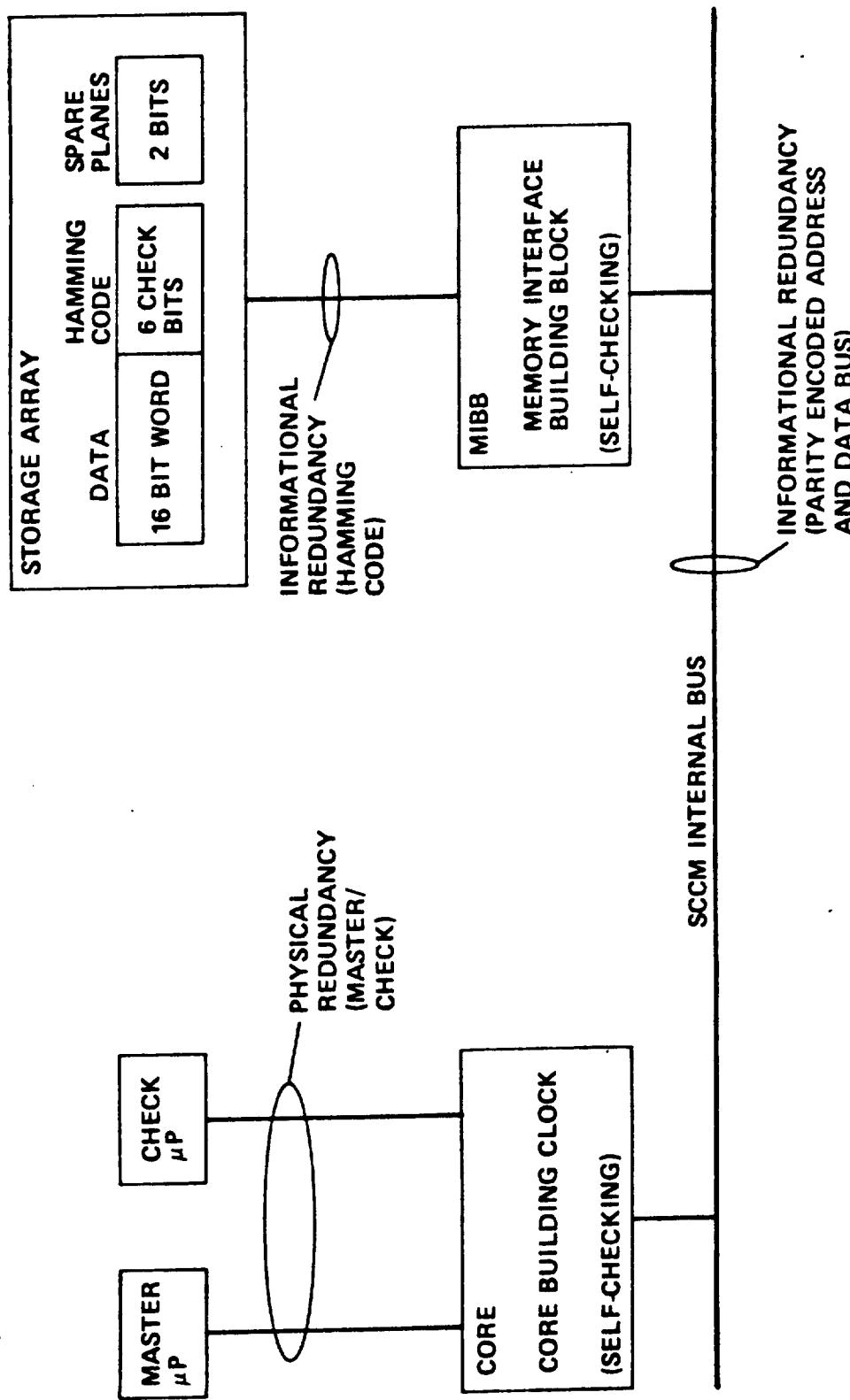
- MODULAR ARCHITECTURE FOR DIVERSE APPLICATIONS
- RELIABLE FOR LONG-LIFE APPLICATIONS
- MODERATE COST AND PERFORMANCE
- LOW POWER
- RADIATION HARDENABLE
- COMPATIBLE WITH VLSI IMPLEMENTATION

SELF-CHECKING COMPUTER MODULE OVERVIEW
RELIABILITY DRIVERS

- DEEP SPACE MISSIONS
 - 5 - 10 YEAR DURATION -- NO REPAIR
 - .99/.95 BASIC/ENHANCED SUCCESS
- SPACE STATION
 - 10 - 20 YEAR LIFE -- INFREQUENT REPAIR
 - LIFE/MISSION CRITICAL
- AIR FORCE SATELLITE -- AUTONOMOUS REDUNDANCY AND MAINTENANCE MANAGEMENT SUBSYSTEM (ARMMS)
 - 6 MONTHS UNATTENDED OPERATION AFTER 5 YEARS ON ORBIT

SELF-CHECKING COMPUTER MODULE OVERVIEW

MODULE FAULT APPROACH



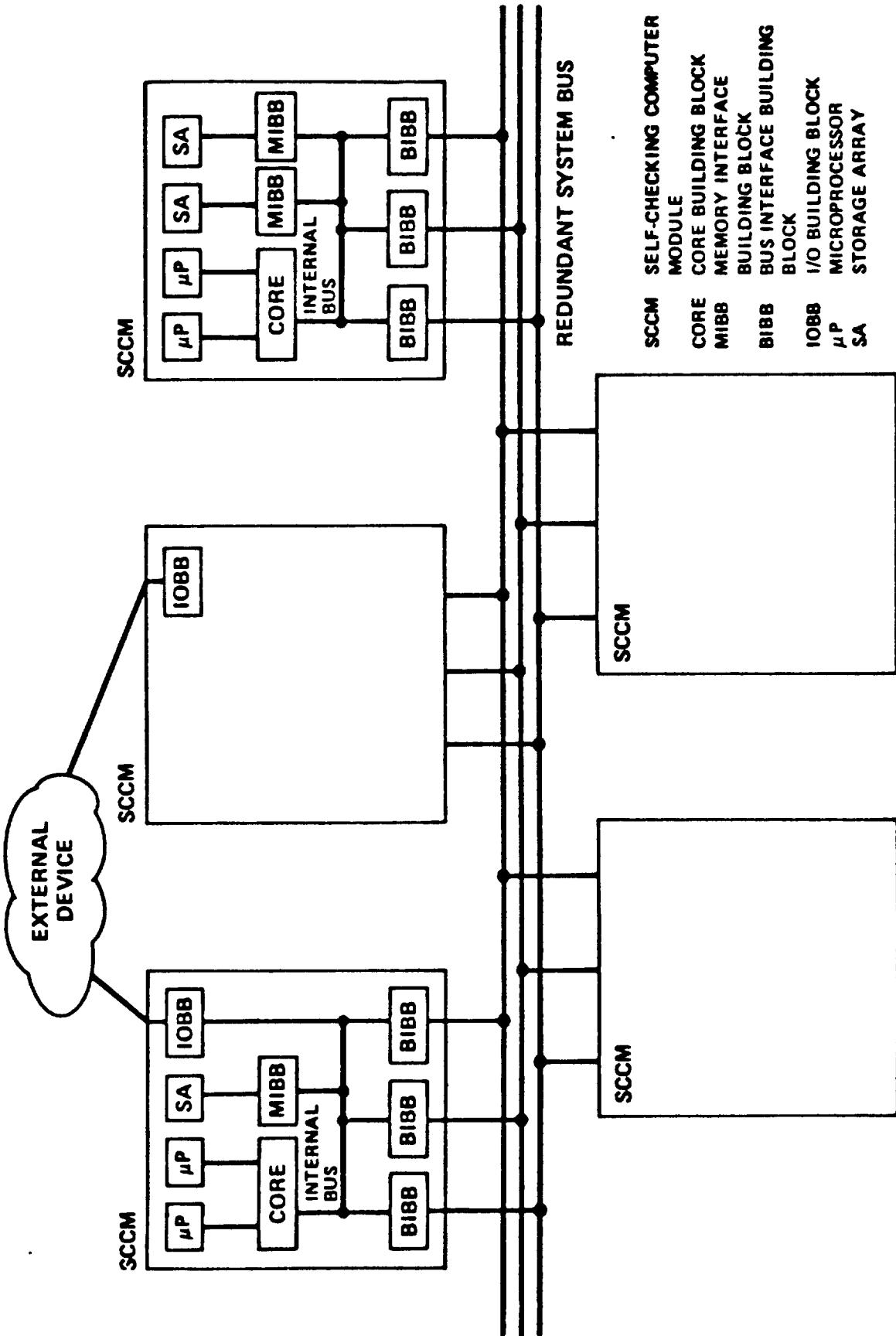
RELIABILITY TECHNIQUES:

- SELF-CHECKING BUILDING BLOCKS
- PHYSICAL REDUNDANCY WITH COMPARISON CHECKING
- INFORMATIONAL REDUNDANCE WITH DECODE CHECKING

SELF-CHECKING COMPUTER MODULE OVERVIEW
MODULE FAULT APPROACH (CONT'D)

- STANDARD MICROPROCESSOR AND MEMORY CHIPS
- HARDWARE FAULT DETECTION (BUILDING BLOCKS)
 - CORE -- PROCESSOR INTERFACE
 - MIBB -- MEMORY INTERFACE
 - BIBB -- EXTERNAL BUS INTERFACE
 - IOBB -- INPUT/OUTPUT
- SOFTWARE CONTROLLED RECOVERY
 - ROLLBACK -- FOR TRANSIENT FAULTS
 - SPARE SWITCHING -- FOR PERMANENT FAULTS

SELF-CHECKING COMPUTER MODULE OVERVIEW SYSTEM FAULT APPROACH

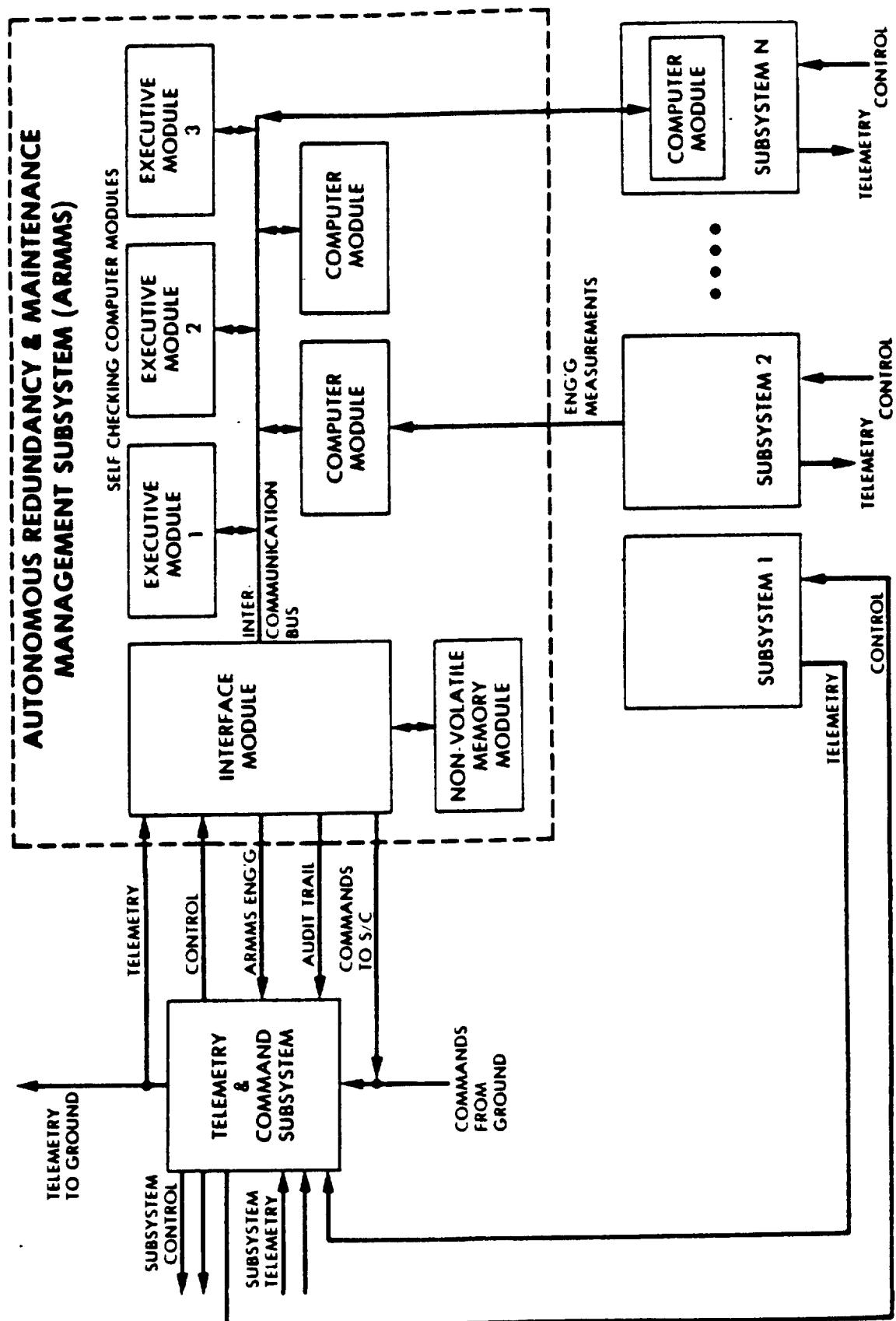


**SELF-CHECKING COMPUTER MODULE OVERVIEW
SYSTEM FAULT APPROACH (CONT'D)**

- SPARING AT COMPUTER MODULE LEVEL
- MODULES RECOVER FROM TRANSIENT FAULTS
- MODULES RECOVER FROM OR SHUT DOWN SAFELY FROM PERMANENT FAULTS
- ALLOW ALTERNATE ARCHITECTURES TO MEET RELIABILITY/PERFORMANCE REQUIREMENTS
- MAINTAIN ACCESS TO UNCORRUPTED CRITICAL DATA IN FAILED MODULES

AUTONOMOUS REDUNDANCY MANAGEMENT SUBSYSTEM DEMONSTRATION

AN APPLICATION OF THE SCCM



SELF-CHECKING COMPUTER MODULE STATUS

- PAST SCCM SPONSORS
 - INFORMATION SCIENCES AND HUMAN FACTORS OFFICE (L. HOLCOMB/RC)
 - COMPUTER SCIENCES RTOP 506-54-55 / R. LARSEN
 - ADVANCED DATA SYSTEMS RTOP 506-58-15 / K. R. WALLGREEN
- NAVY - NMSC
- PAST ARMM'S SPONSOR
 - AIR FORCE - SPACE DIVISION, SPACE TECHNOLOGY CENTER
- TASK LEADERS
 - SCCM - DANIEL ERICKSON, DWIGHT GEER
 - ARMM'S - WAYNE ARENS
- PROGRESS
 - SCCM - CORE & MIBB BREADBOARDED AND DEMONSTRATED
 - BIRB DETAILED DESIGN STARTED
 - ARMM'S - PRELIMINARY DESIGN COMPLETED
- POSSIBLE NEW SPONSOR
 - ARMY - BALLISTIC MISSILE DEFENSE OFFICE, ADVANCED TECHNOLOGY CENTER

ON-LINE SELF-TEST DESIGN TECHNIQUES FOR VLSI & GATE-ARRAY CIRCUIT TECHNOLOGY

OVERVIEW - WHY IMPORTANT?

- MANY FAULT TOLERANT SYSTEMS RECOVER FROM SINGLE FAULTS ONLY IF FAULTS ARE DETECTED AS SOON AS THEY OCCUR
- FAULTS CAN BE UNDETECTED WHEN PART OF THE SYSTEM IS UNUSED DURING NORMAL OPERATIONS
- SYSTEMS CAN SUSPEND NORMAL OPERATION IN ORDER TO TEST UNEXERCISED PARTS
- NOT PRACTICAL DURING CRITICAL TASKS
- THEREFORE, NEED FOR CONCURRENT SELF-TEST TECHNIQUES WHICH HAVE ONLY INSIGNIFICANT IMPACT ON NORMAL SYSTEM OPERATIONS

ON-LINE SELF-TEST DESIGN TECHNIQUES FOR VLSI & GATE-ARRAY CIRCUIT TECHNOLOGY
TECHNICAL OVERVIEW

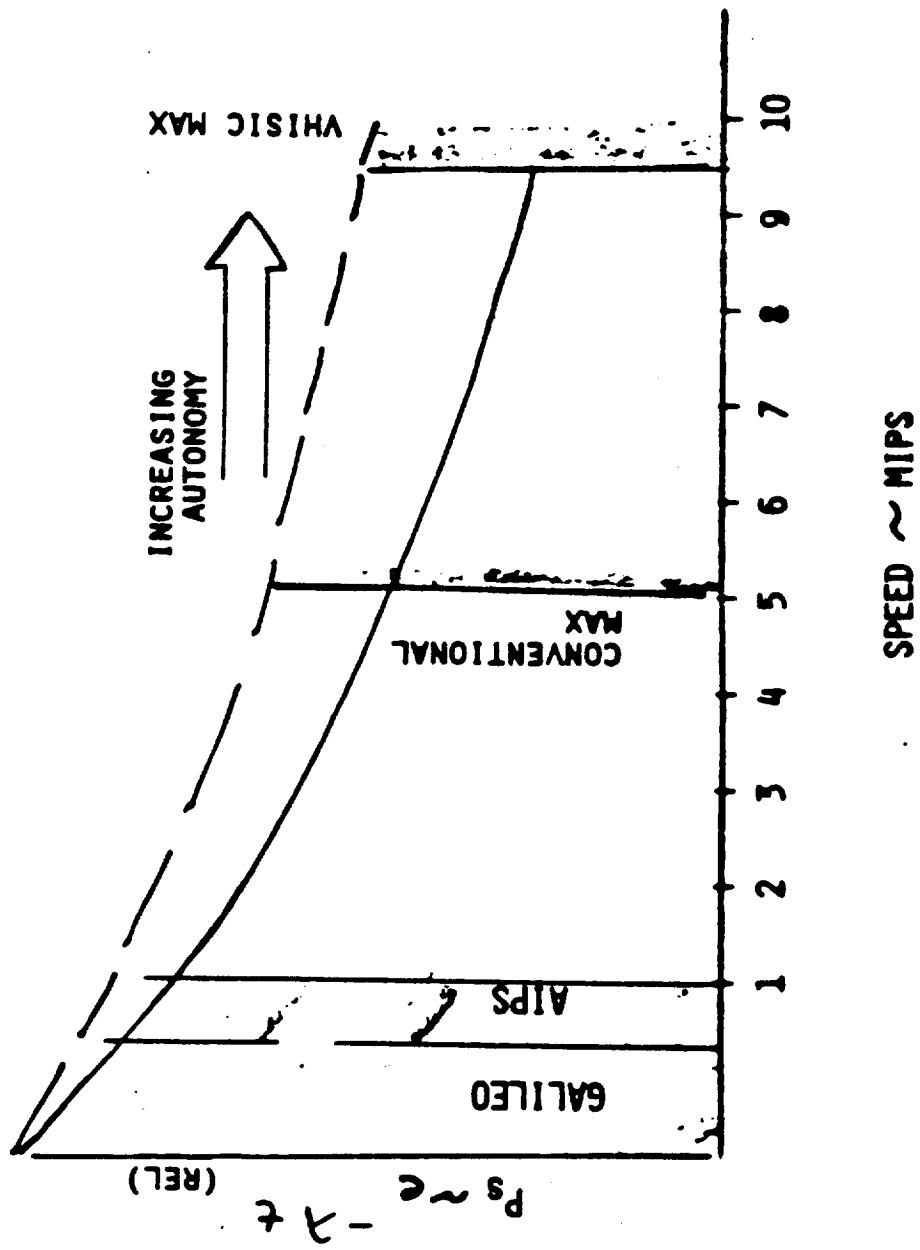
- OBJECTIVE - DEVELOP ON-LINE SELF-TESTING TECHNIQUES WHICH CAN IMPROVE RELIABILITY/AVAILABILITY OF DATA SYSTEMS
- SUBTASK #1 - DEVELOP METHODS FOR DESIGN OF ON-LINE SELF-TEST
 - IDENTIFY COMMON GENERIC VLSI/GATE-ARRAY (CMOS) BUILDING BLOCKS (E.G. RAM, PLA, ALU) AND THEIR FAULT MODELS
 - DEVELOP CONCURRENT SELF-TESTING FOR THESE BUILDING BLOCKS
 - DEVELOP METHODS TO INTEGRATE TECHNIQUES INTO FAULT TOLERANT VLSI/GATE-ARRAY SYSTEMS
- SUBTASK #2 - DEVELOP METHODS TO EVALUATE EFFECTIVENESS OF ON-LINE SELF-TEST DESIGN TECHNIQUES
 - DEVISE AND EXECUTE EXPERIMENTS TO EVALUATE EFFECTIVENESS OF BUILT-IN RANDOM TESTING TECHNIQUES (PROGRAMMABLE LFSR AND MISR) FOR SINGLE AND MULTIPLE FAULT COVERAGE OF TYPICAL CIRCUITS
 - DEVELOP COMPUTER BASED UNIFIED ANALYTICAL MATHEMATICAL MODEL TO ANALYZE TESTABILITY AT ALL LEVELS OF A SYSTEM
 - DEVELOP RELIABILITY MODELING AND ANALYSIS METHODS FOR CONCURRENT SELF-TESTING SYSTEMS (AND INCORPORATE INTO ARIES)
- SUBTASK #3 - TRANSFER RESEARCH RESULTS TO OTHER PROJECTS
 - CALTECH/JPL CONCURRENT COMPUTING PROJECT (MARK III HYPERCUBE)
 - ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER

ON-LINE SELF-TEST DESIGN TECHNIQUES FOR VLSI & GATE-ARRAY CIRCUIT TECHNOLOGY
STATUS

- SPONSORS
 - OAST - INFORMATION SCIENCES AND HUMAN FACTORS OFFICE (L. HOLCOMB/RC)
 - ADVANCED DATA SYSTEMS RTOP 506-58-15 / K. R. WALLGREN
 - CALTECH/JPL - MARK III HYPERCUBE / D. CURKENDALL
- TASK LEADER - SAVIO CHAU
- PROGRESS
 - DESIGNED A CLASS OF SELF-EXERCISING COMBINATIONAL CIRCUITS
 - DEVELOPED S/W DESIGN TOOL FOR PROBABILISTIC ANALYSIS OF RANDOM TESTING
 - END-TO-END GATE ARRAY DESIGN CAPABILITY ESTABLISHED
 - SOME COMMON GENERIC VLSI/GATE-ARRAY BUILDING BLOCKS AND THEIR FAULT MODELS HAVE BEEN IDENTIFIED
 - DEVELOPING CONCURRENT SELF-TESTING TECHNIQUES FOR RAM AND PLA
 - BEGINNING TRANSFER OF RESULTS TO MARK III HYPERCUBE GATE-ARRAY DEVELOPMENT
 - ANTICIPATING TRANSFER OF RESULTS TO ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER GATE-ARRAY/STANDARD CELL DEVELOPMENT

ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER OVERVIEW
WHY IMPORTANT?

GENERAL PURPOSE COMPUTER



ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER OVERVIEW
CHARACTERISTICS

- **Embedded, real-time applications**
- **Both synchronous, cyclic operation and asynchronous, event driven operation**
- **Both computationally intensive (e.g. signal processing, guidance) and data intensive (e.g. command and telemetry) processing**
- **Wide range of throughput and memory requirements**
- **Range of fault tolerance requirements from none to full, uninterruptable operation through faults or damage**
- **Maintainability, including capability for on-line substitution in critical systems**

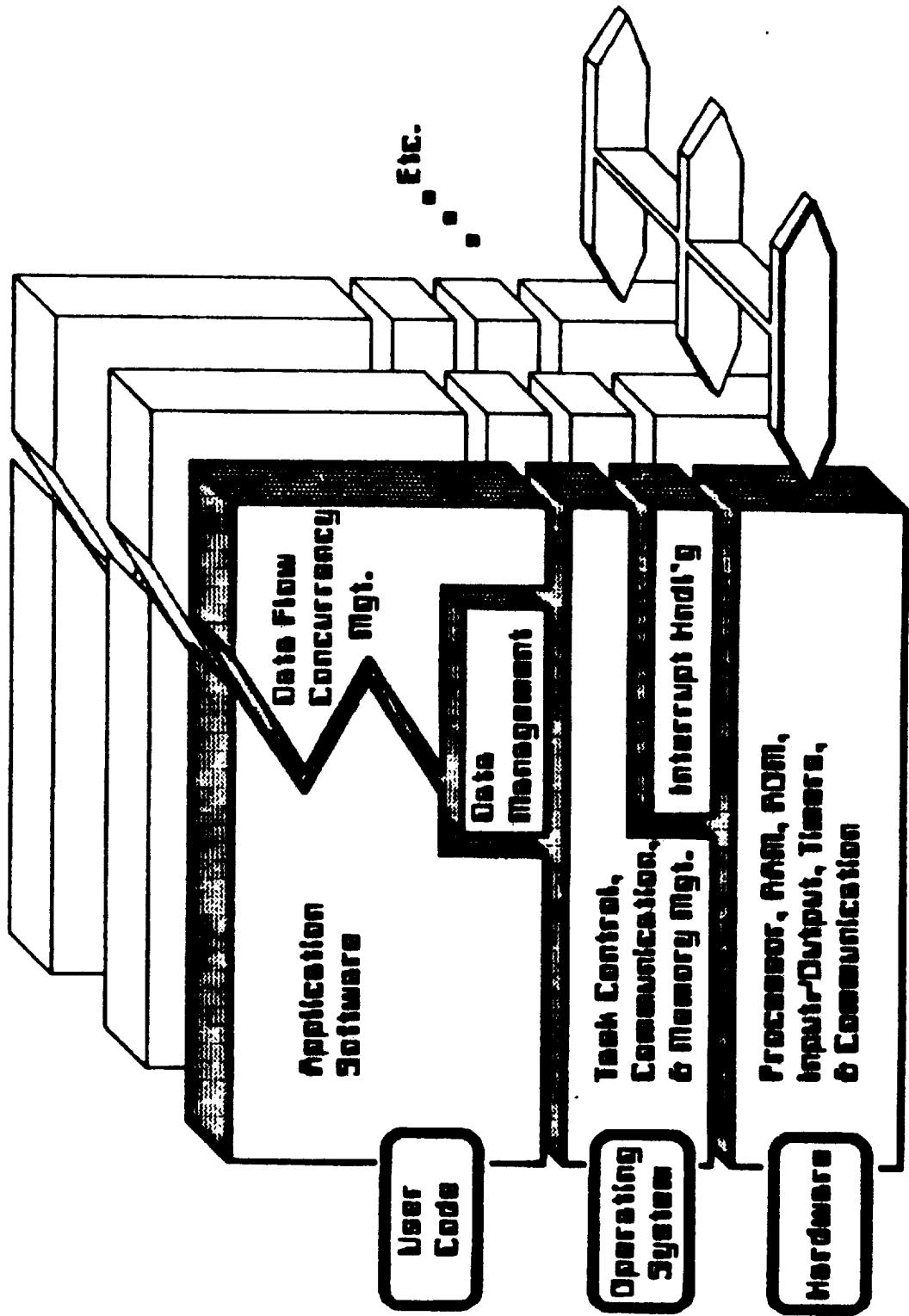
ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER OVERVIEW
HARDWARE FEATURES

- **General purpose computer module**
 - Small, light weight, & low power
 - Radiation hard & single event upset immune
 - ≈ 1 Million Whetstone equivalent instructions per second (floating point)
 - 256 Kbytes (expandable) memory
 - High speed communication ports & memory mapped I/O
 - Global semaphore capability without shared memory
- **Special features support**
 - Multi-computer concurrency
 - Software implemented fault tolerance
 - Spatial distribution for damage tolerance

ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER OVERVIEW
SOFTWARE FEATURES

- Conventional programming and test environments
- Layered software design supporting
 - high level languages
 - real time, multi-tasking & task migration
 - packet communication
 - data management
 - concurrency
 - fault tolerance
- Optional low resolution data-flow concurrency support

ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER OVERVIEW
LAYERED ARCHITECTURE



ADVANCED GENERAL PURPOSE HIGH SPEED COMPUTER STATUS

- SPONSOR
 - OAST - INFORMATION SCIENCES AND HUMAN FACTORS OFFICE (L. HOLCOMB/RC)
 - ADVANCED DATA SYSTEMS RTOP 506-58-15 / K. R. WALLGREEN
- JOINT JPL AND LARC ACTIVITY
 - JPL - DEVELOP ARCHITECTURE AND OPERATING SYSTEM
 - DEVELOP BACKUP BREADBOARD
 - LARC - INTEGRATE ARCHITECTURE WITH VHSIC TECHNOLOGY
 - DEVELOP VHSIC BREADBOARD
- TASK LEADERS
 - JPL - DAVID SMITH LARC - HARRY BENZ
- PROGRESS
 - JPL - COMPLETING ARCHITECTURE DESIGN
 - CONTINUING PROTOTYPE DEVELOPMENT
 - AUGUST/SEPTEMBER DEMONSTRATION
 - LARC - NEARING DELIVERY AND DEMONSTRATION OF VHSIC CHIPS

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